Representation of Top-of-Atmosphere Radiative Flux Changes in Current Reanalyses

Hailan Wang[1], Norman G. Loeb[2]

[1]SSAI, [2]NASA Langley Research Center

Acknowledgement: Michael Bosilovich (NASA/GMAO)

Spring 2019 CERES Science Team Meeting

7-9 May 2019, Hampton VA

Introduction

- What is a reanalysis?
  - A global best estimate of atmospheric, land and oceanic parameters obtained by optimally combining model and observations
    - Cloud and radiation fields are produced by the assimilating model while the model basic state variables are constrained by various observations via data assimilation technique, and thus depend on the model performance and the observations input to the assimilation
  - used for a variety of applications, such as:
    - various weather and climate studies
    - development and verification of climate models

Global mean of TOA all-sky radiative fluxes

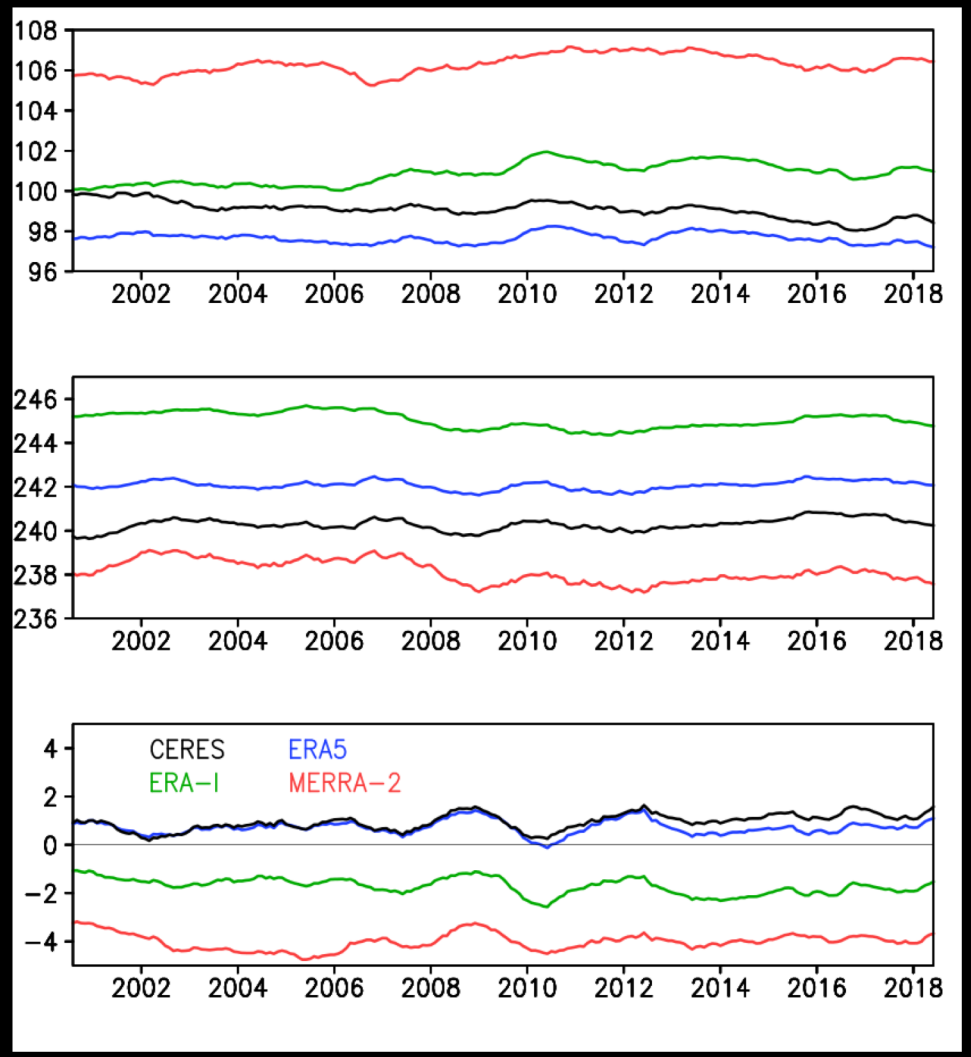
12-Month RunMean

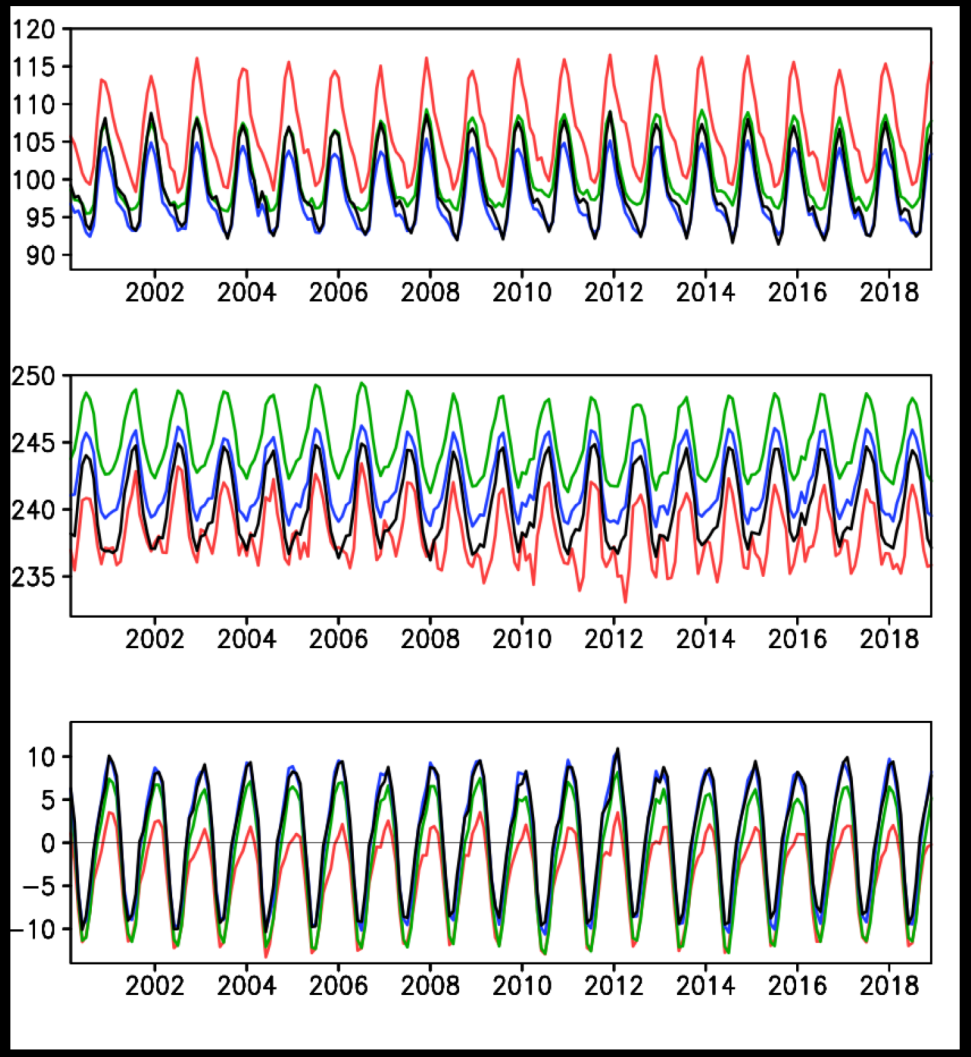
Monthly

SW↑

LW↑

Net↓





CERES **ERA5** **ERA-Interim** **MERRA-2**

➢ A typical reanalysis evaluation looks like this…

Global mean of TOA all-sky radiative fluxes

12-Month RunMean

SW↑

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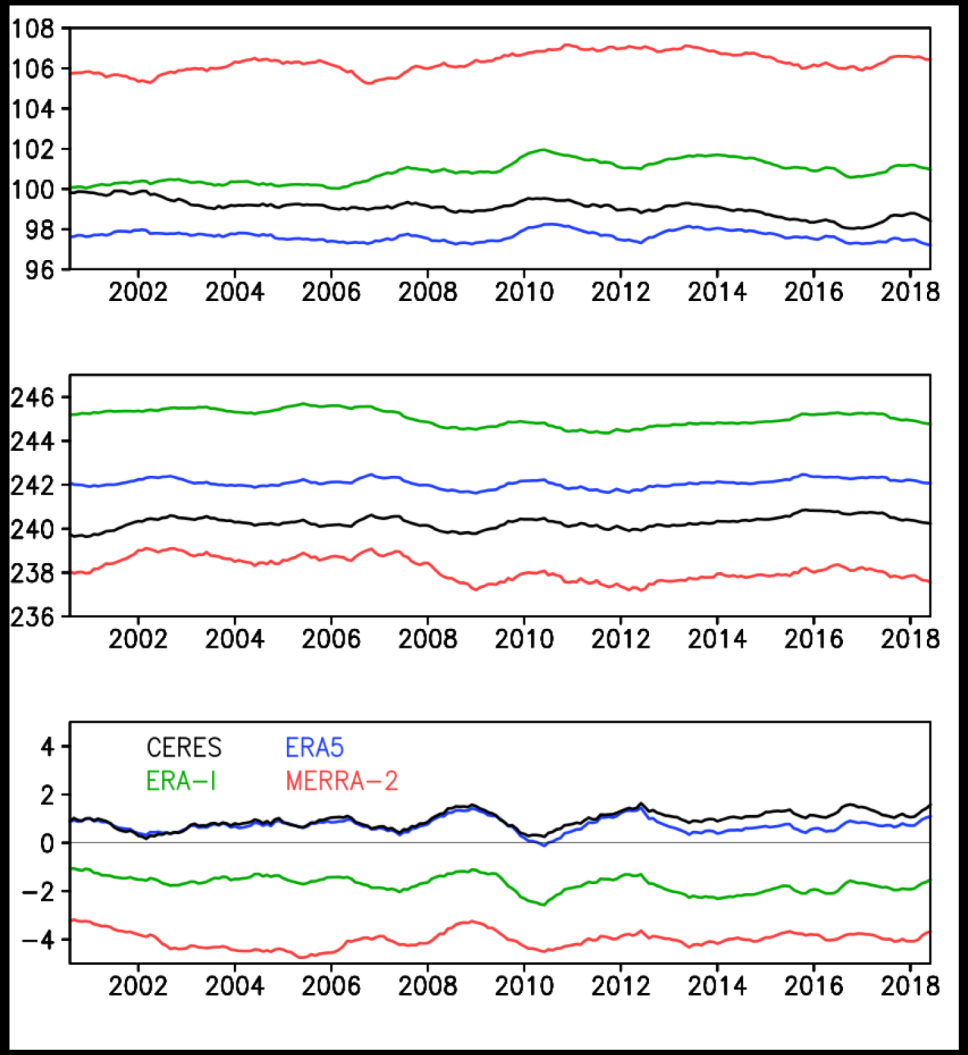


CERES **ERA5** **ERA-Interim** **MERRA-2**

Global mean of ***Clim*** TOA all-sky fluxes: minus CERES

TOA All-Sky Fluxes (Wm^{-2})	ERA5	ERA-Interim	MERRA-2
SW↑	-1.4	1.8	7.2
LW↑	1.8	4.8	-2.1
Net↓	-0.2	-2.6	-5.0

➢ Reanalysis deviations from CERES: Clim + Variations

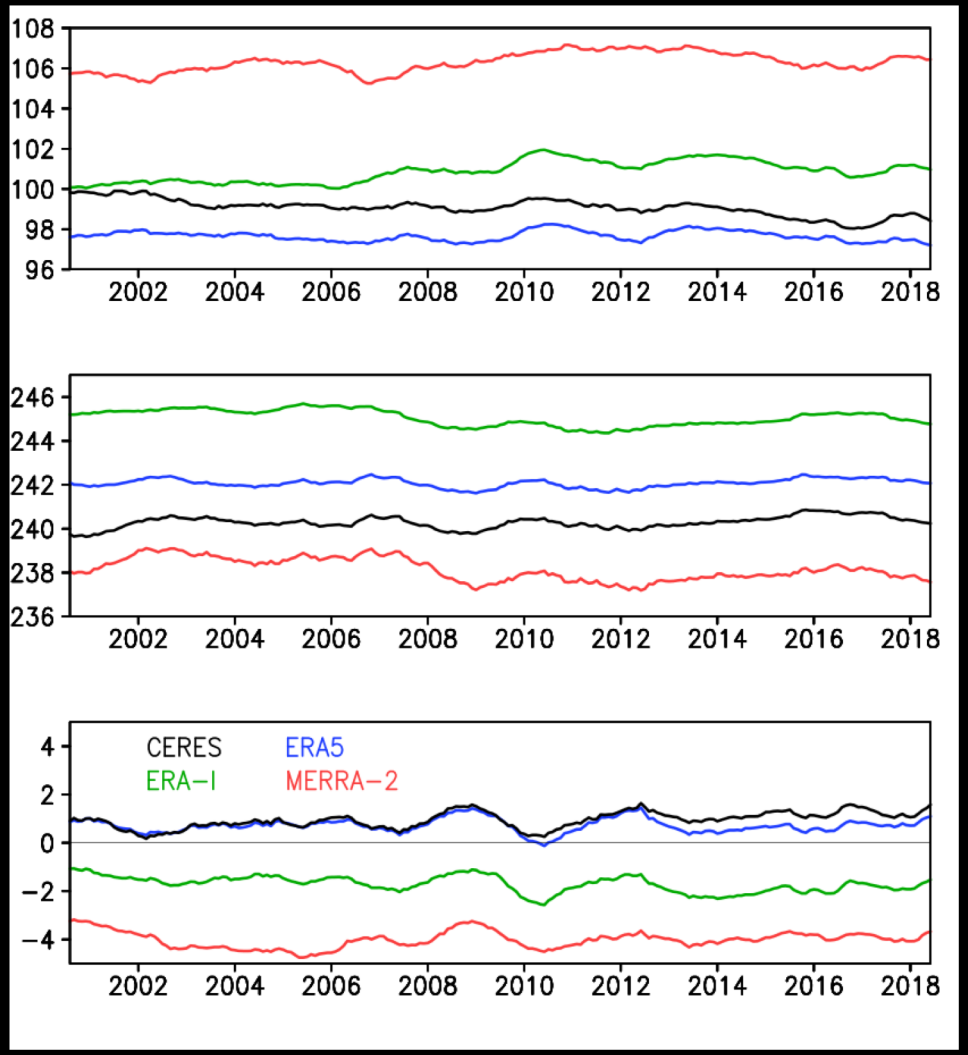
Global mean of TOA all-sky radiative fluxes

12-Month RunMean

SW↑

LW↑

Net↓



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Focus of this study: **variations**

Global mean of *deseasonalized* TOA all-sky radiative fluxes

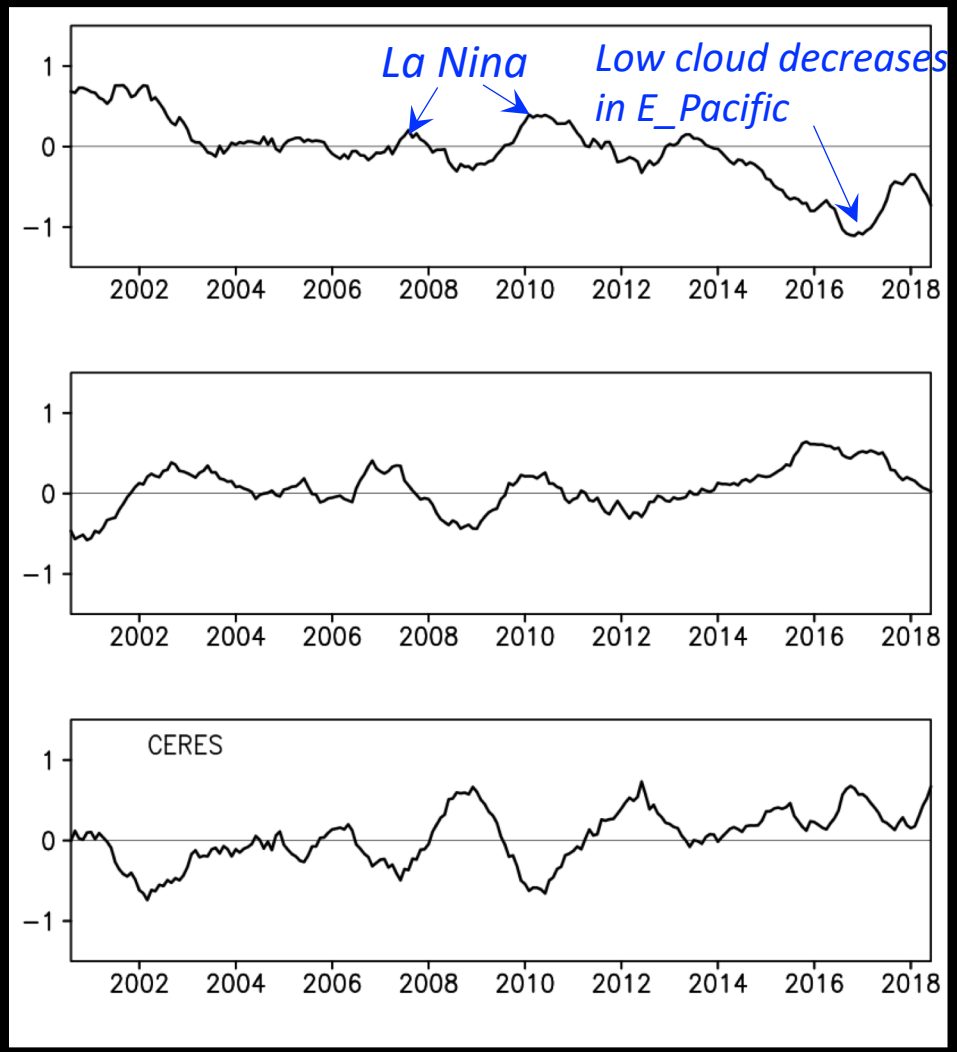
12-Month RunMean

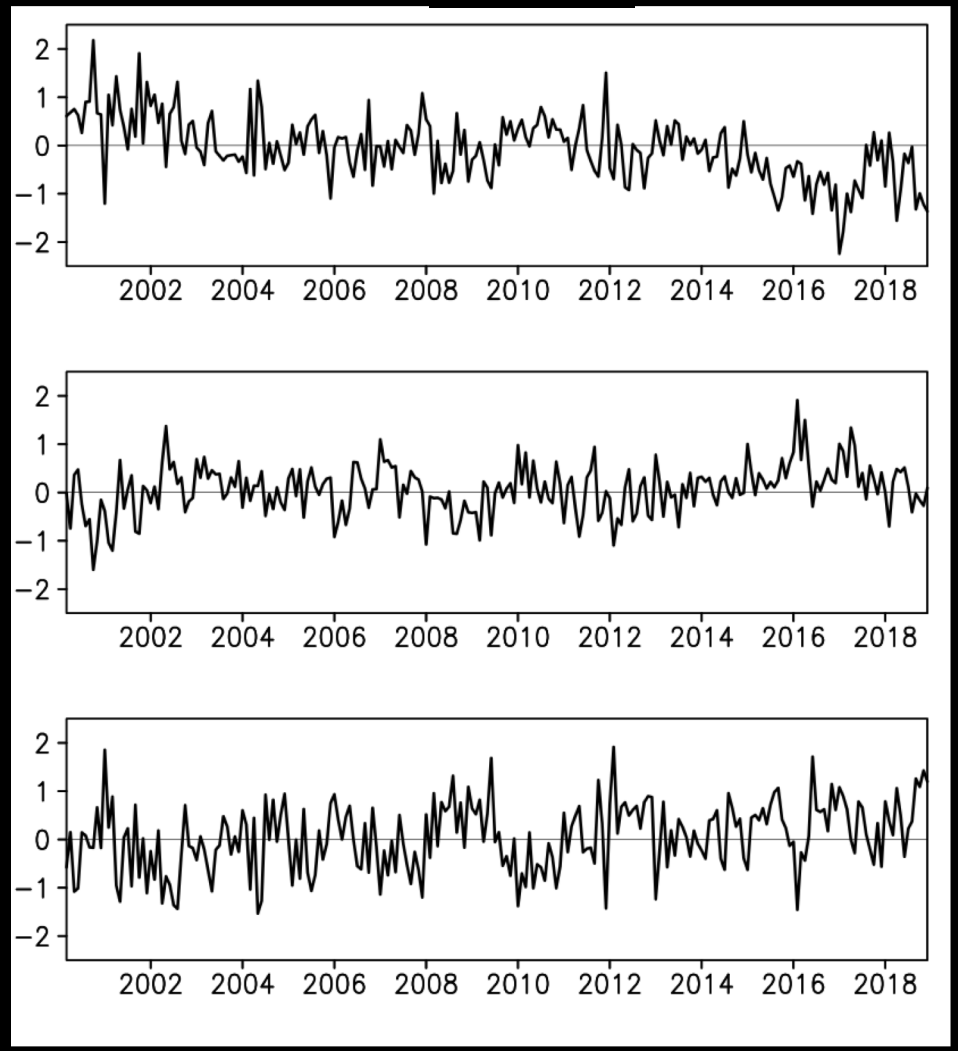
Monthly

SW↑

LW↑

Net↓





CERES

- CERES: the variations of global mean TOA fluxes are largely determined by cloud changes associated with the changes in low boundary conditions (e.g. SST).

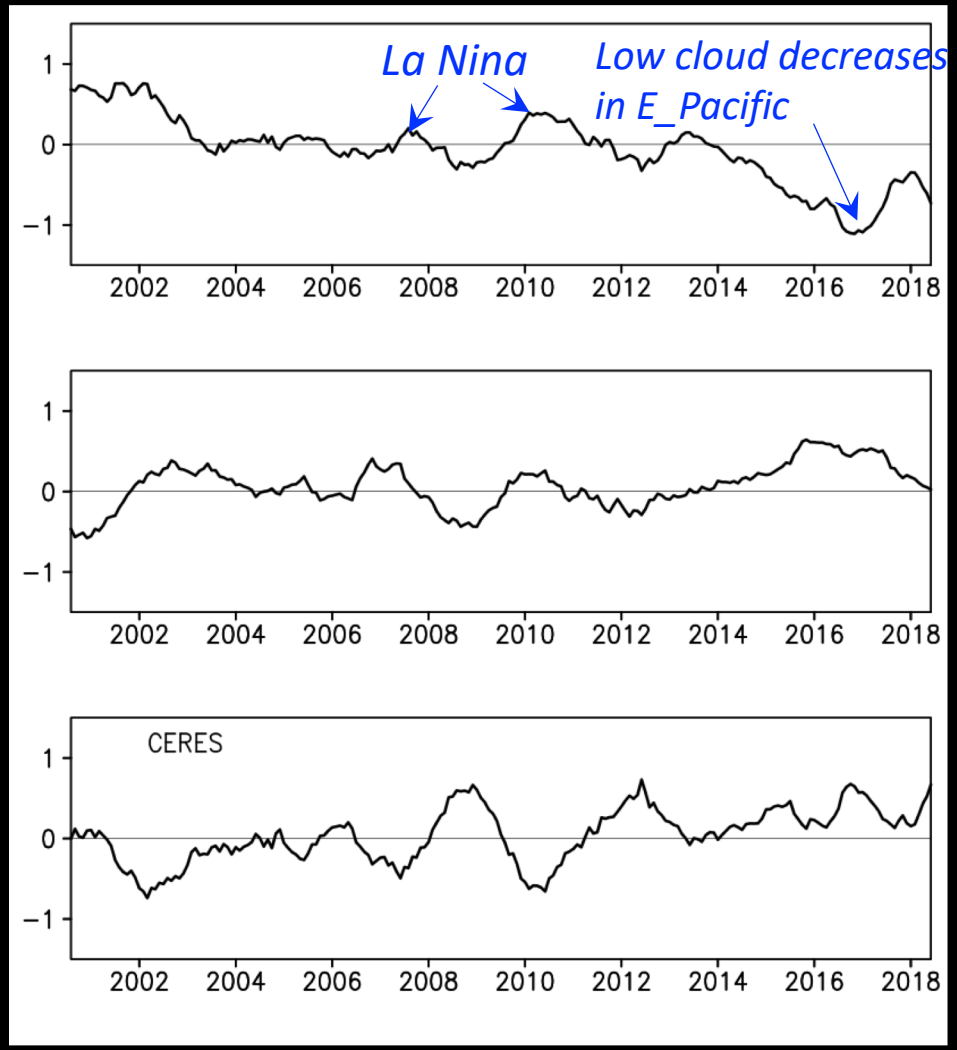
Global mean of *deseasonalized* TOA all-sky radiative fluxes

12-Month RunMean

SW↑

LW↑

Net↓



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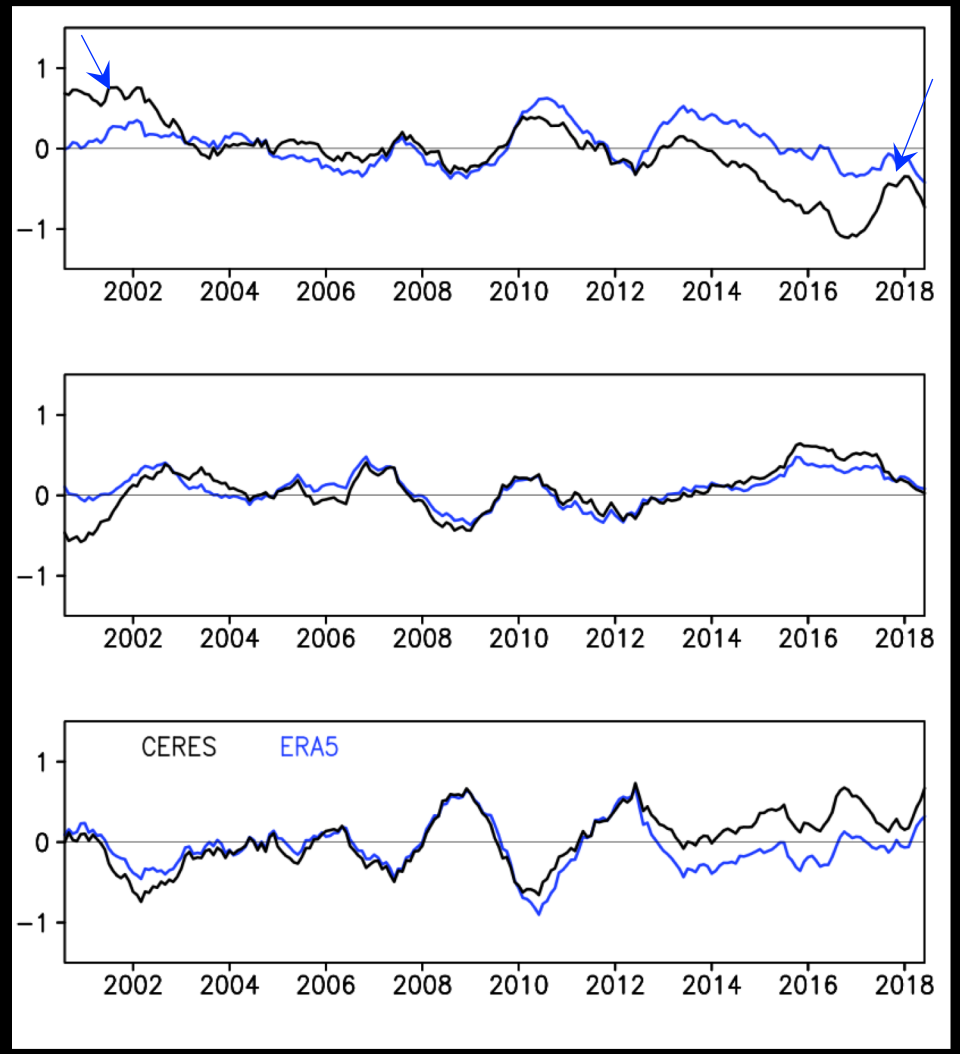

CERES **ERA5**

- The observed post-hiatus TOA SW↑ decrease is associated with considerable low cloud reductions in the NE_Pacific (Loeb *et al*. 2018).
- ERA5: captures the observed variations except that it underestimates the post-hiatus SW↑ and hence Net↓ anomaly.

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12-Month RunMean

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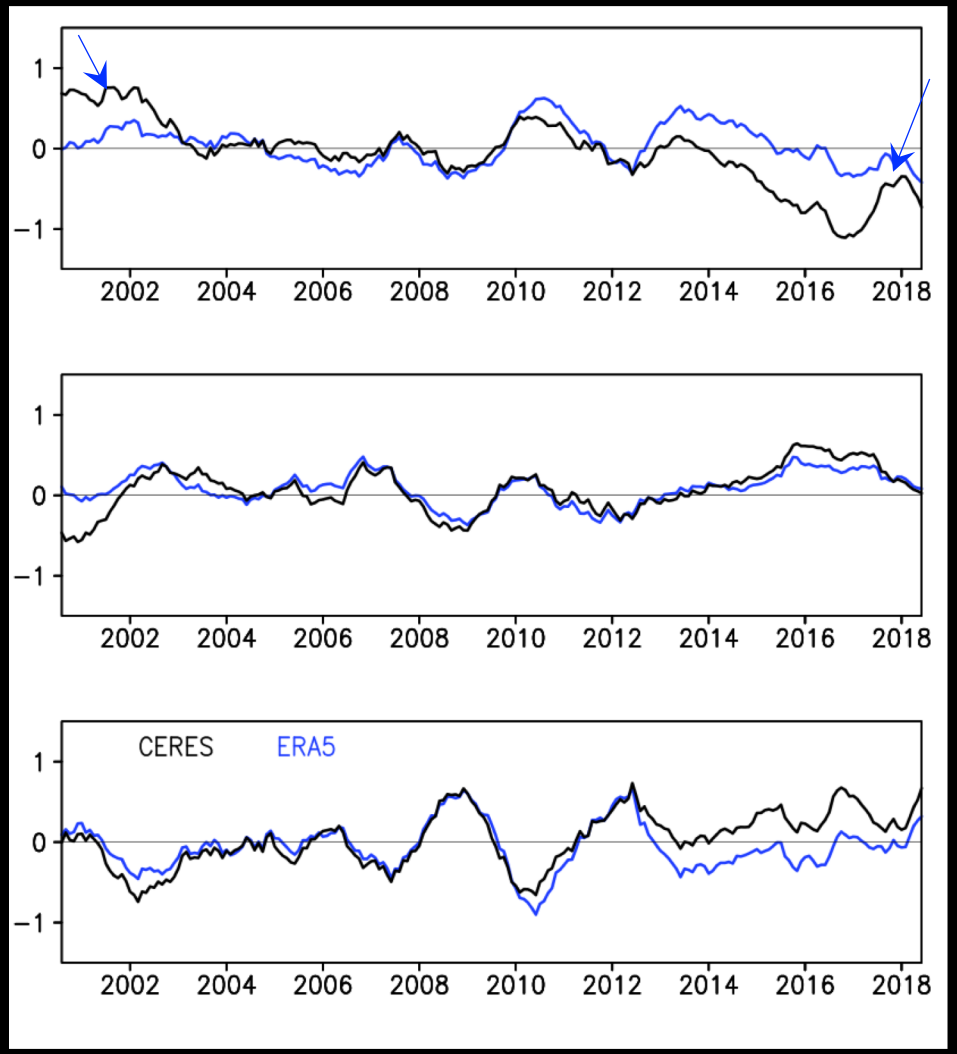
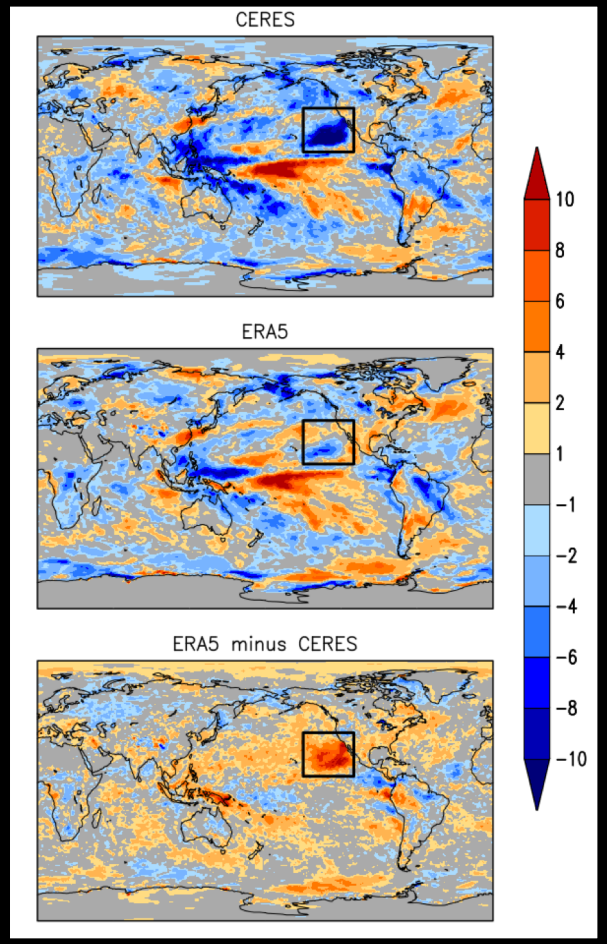


CERES **ERA5**

SW↑:
Clim(07/2014-06/2017) minus
Clim(07/2000-06/2014)



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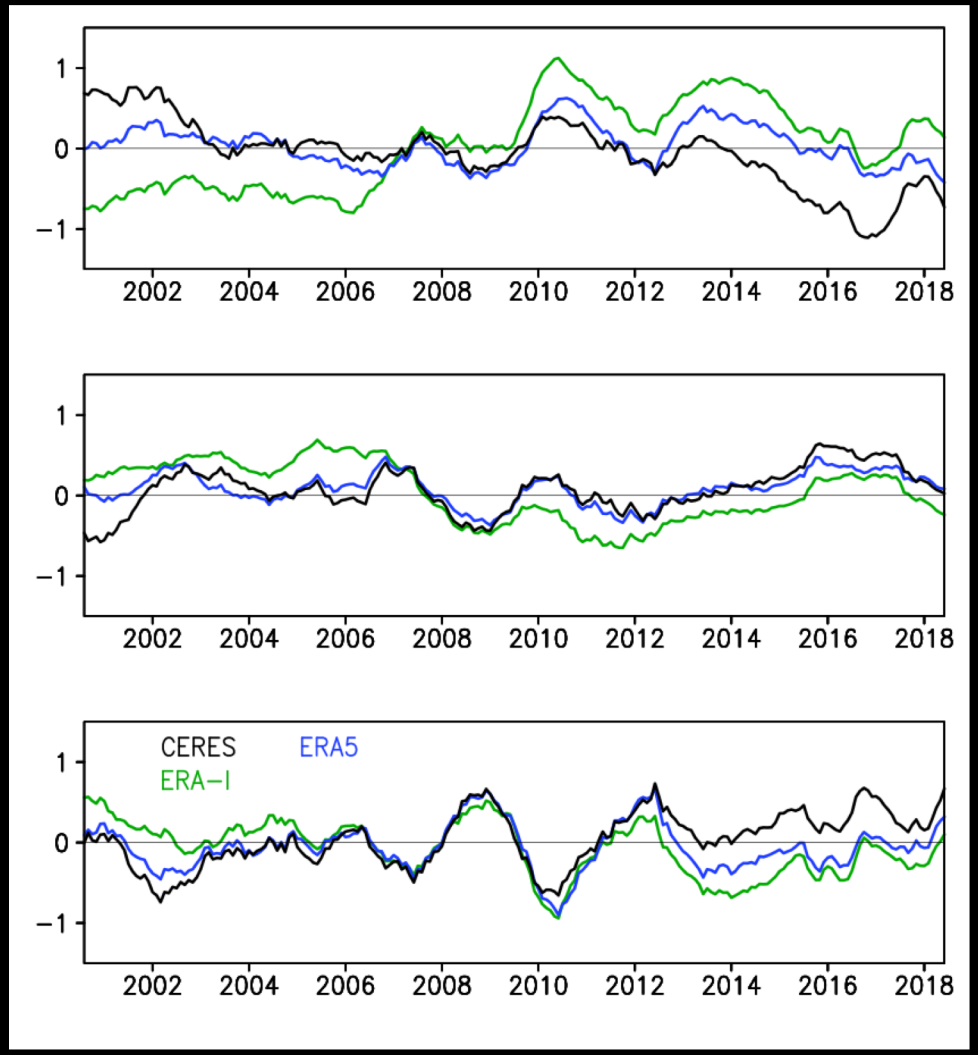


CERES **ERA5** **ERA-Interim**

- ERA-5: captures the observed variations except that it underestimates the post-hiatus SW↑ and hence Net↓ anomaly; shows considerable improvement upon ERA-I.
- ERA-Interim (ERA-I): deviations from CERES have opposite signs before and after ~2009/10.

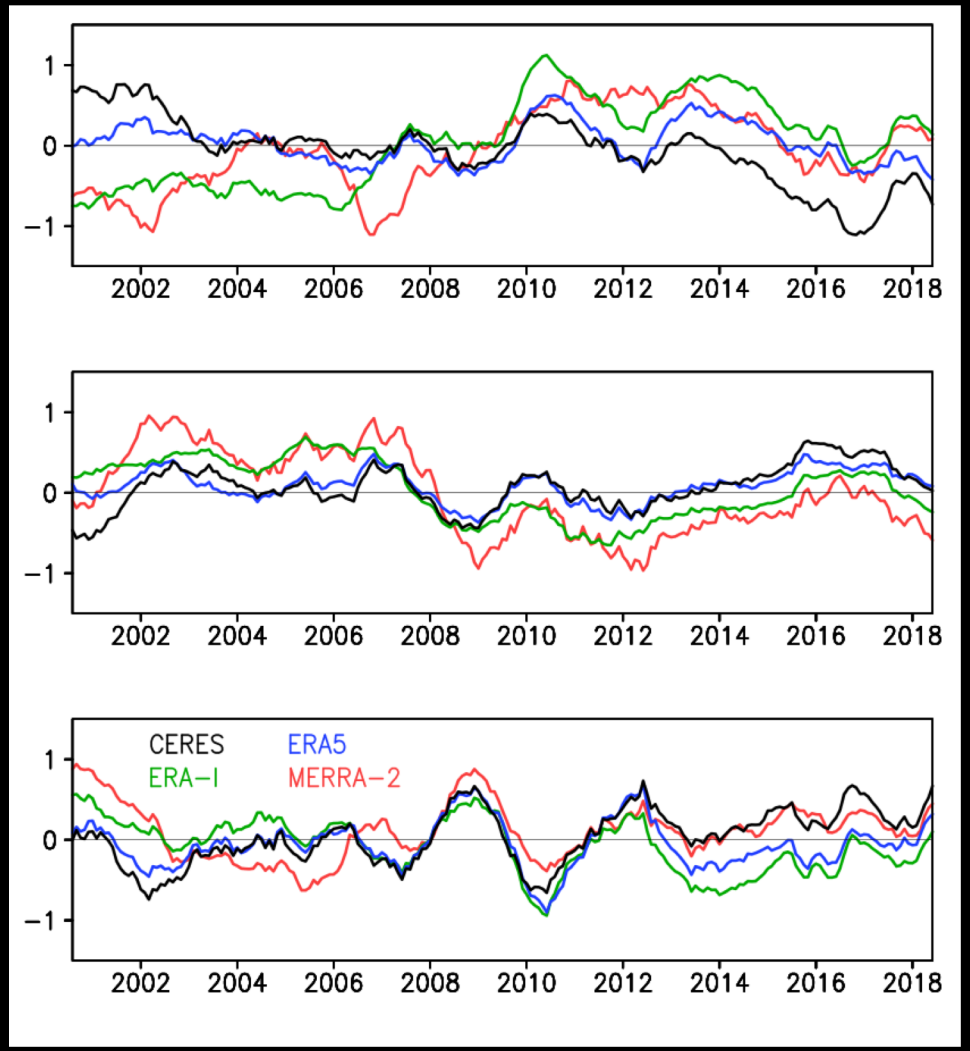
Global mean of *deseasonalized* TOA all-sky radiative fluxes

12-Month RunMean

SW↑

LW↑

Net↓



CERES **ERA5** **ERA-Interim** **MERRA-2**

- ERA-5: captures the observed variations except that it underestimates the post-hiatus SW↑ and hence Net↓ anomaly; shows considerable improvement upon ERA-I.
- ERA-Interim (ERA-I): deviations from CERES have opposite signs before and after ~2009/10.
- MERRA-2: deviations from CERES are similar to those in ERA-I.

Global mean of *deseasonalized* TOA all-sky radiative fluxes

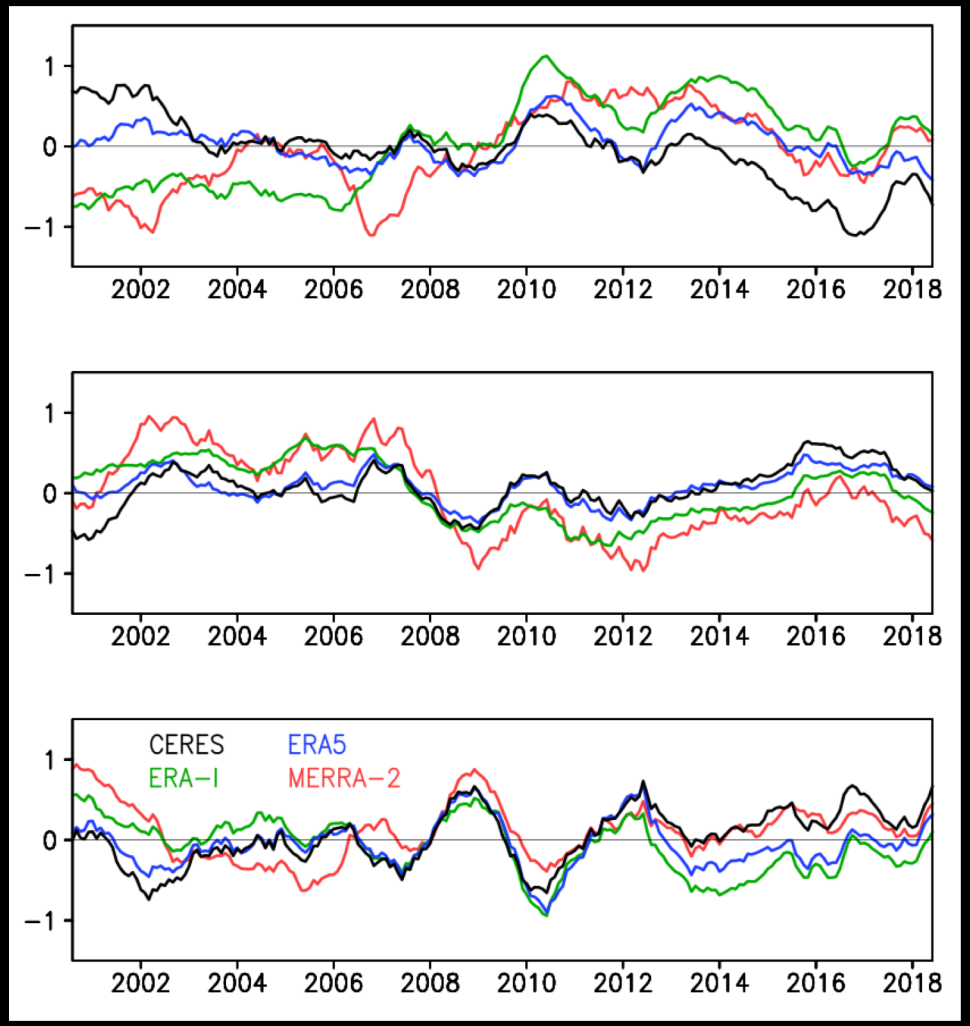
Wrt 2003-2014Clim

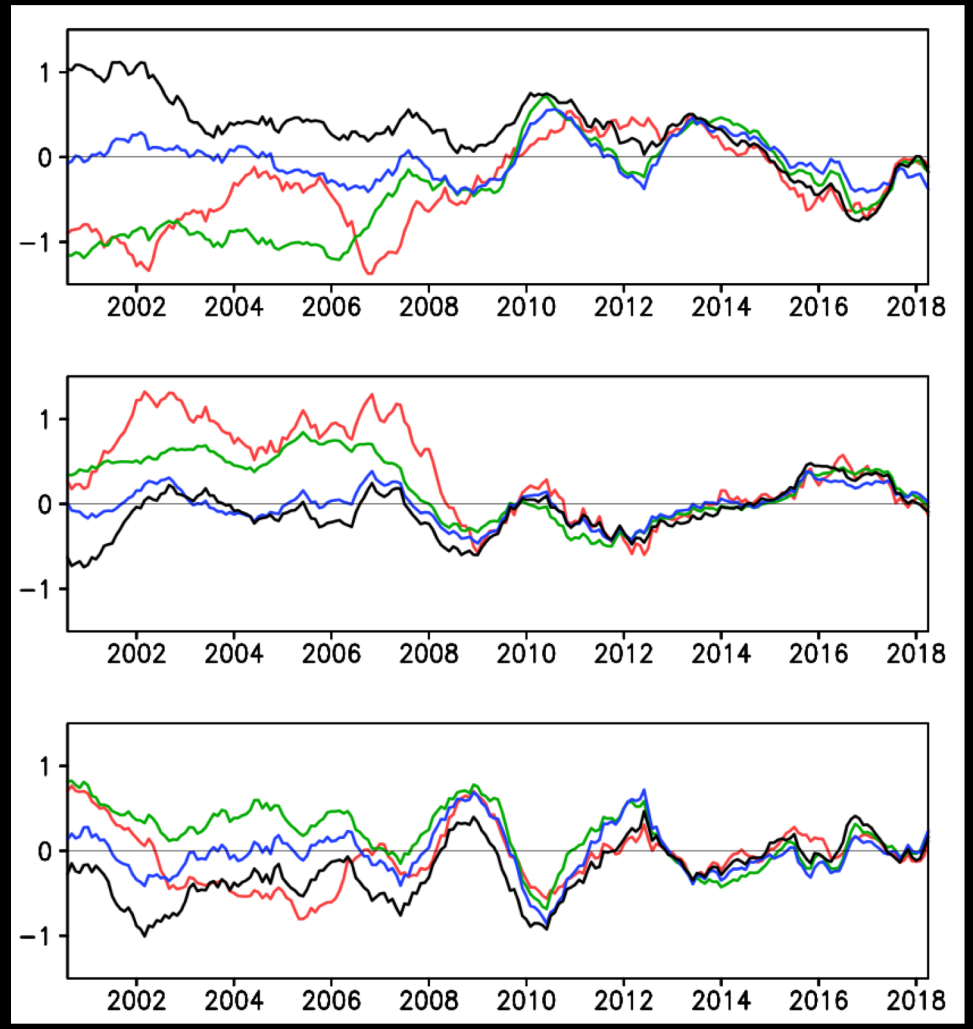
Wrt 2011-2018Clim

SW↑

LW↑

Net↓





CERES **ERA5** **ERA-Interim** **MERRA-2**

- The pre- vs. post-2010 differences can be highlighted by showing anomalies as deviations from the post-2010 clim.

Global mean of *deseasonalized* TOA all-sky radiative fluxes

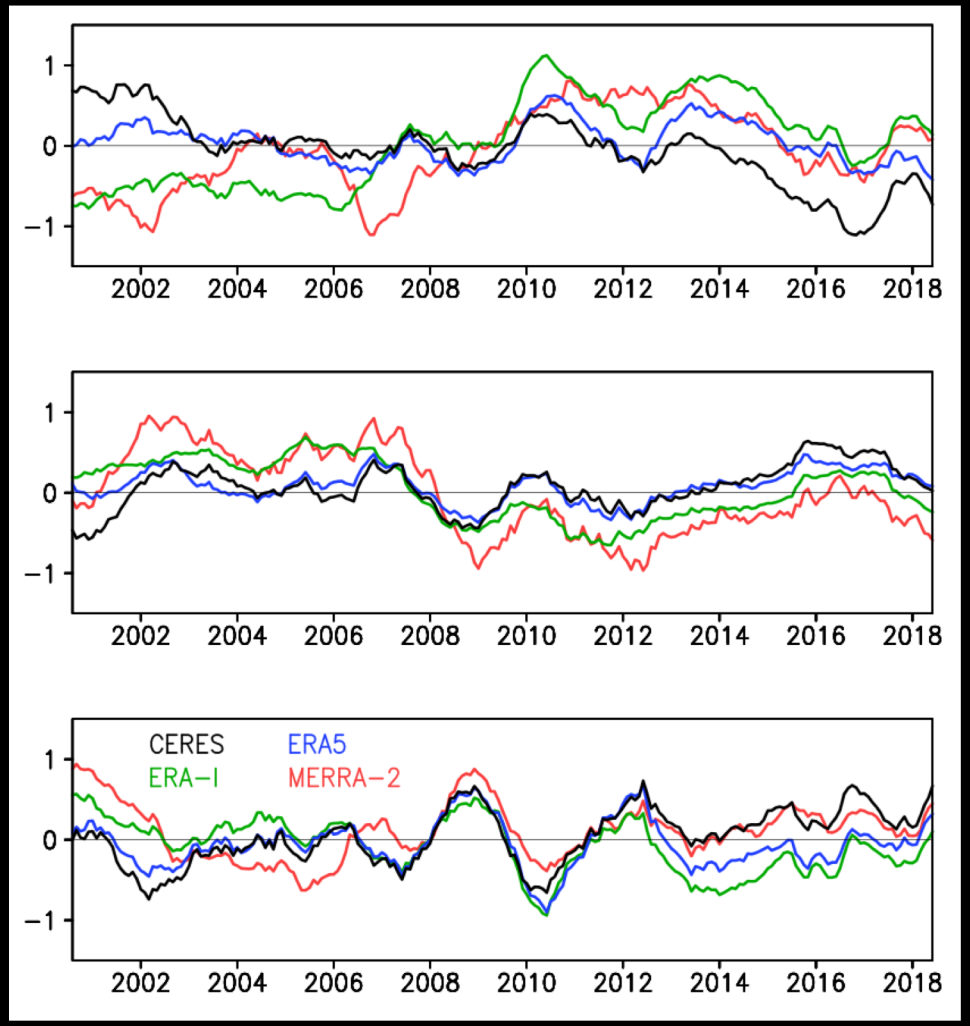
Wrt 2003-2014Clim

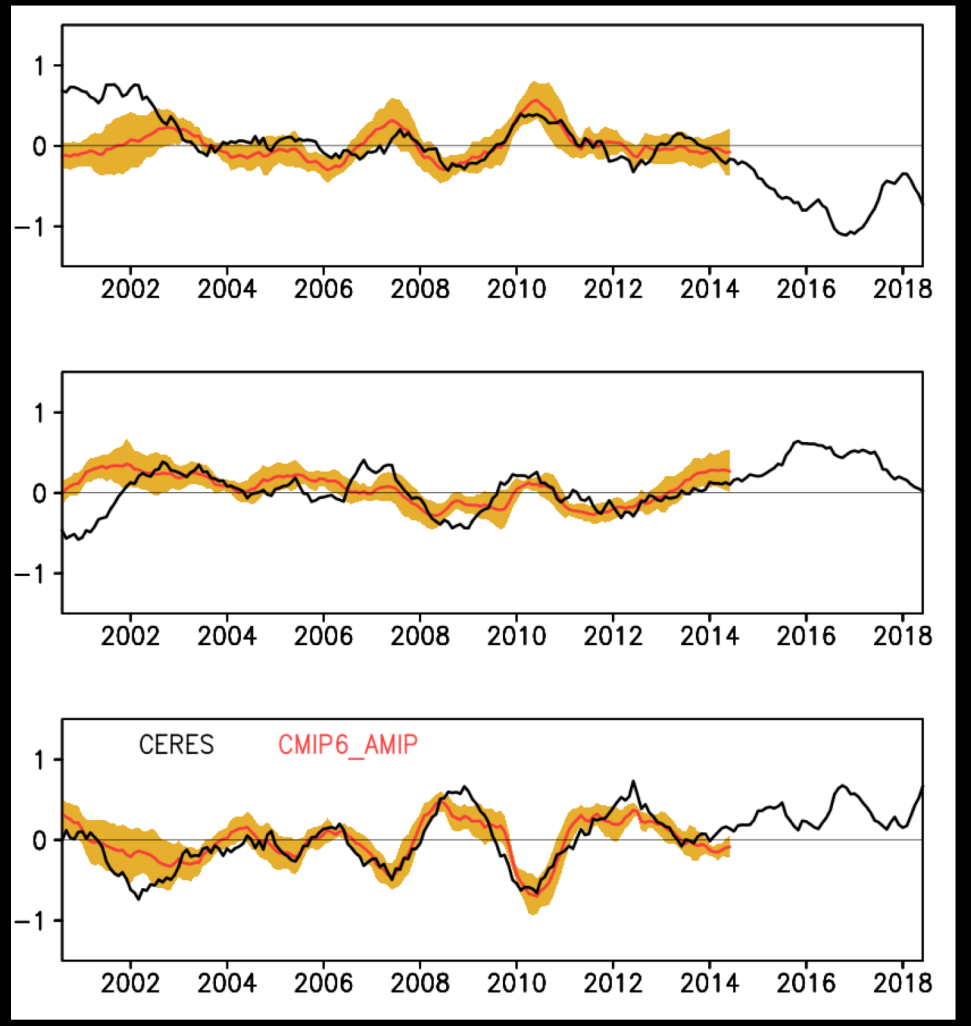
Wrt 2003-2014Clim

SW↑

LW↑

Net↓





CERES **ERA5** **ERA-Interim** **MERRA-2** **CMIP6_AMIP**

➢ CMIP6 AMIP performs better than reanalyses.

Reanalyses	Data Availability	
	AMIP	Reanalysis that assimilates consistent surface obs
ERA-Interim	ERA-20CM*	ERA-20C*
MERRA-2	M2AMIP	

* Used more advanced IFS than ERA-I
* Data are only available through 12/2010

Data	Variations of TOA all-sky radiative fluxes are affected by *changes in*		
	SST and sea ice	Obs assimilation	Atmospheric internal variability
Reanalyses	Y	Y	weakly
AMIP	Y	N	Y
Reanalyses_SurfaceObs	Y	N	moderately

- The impact of input changing observing systems on reanalyses can be investigated by comparing reanalyses with their parallel AMIP simulations and/or reanalyses that assimilate consistent observations.

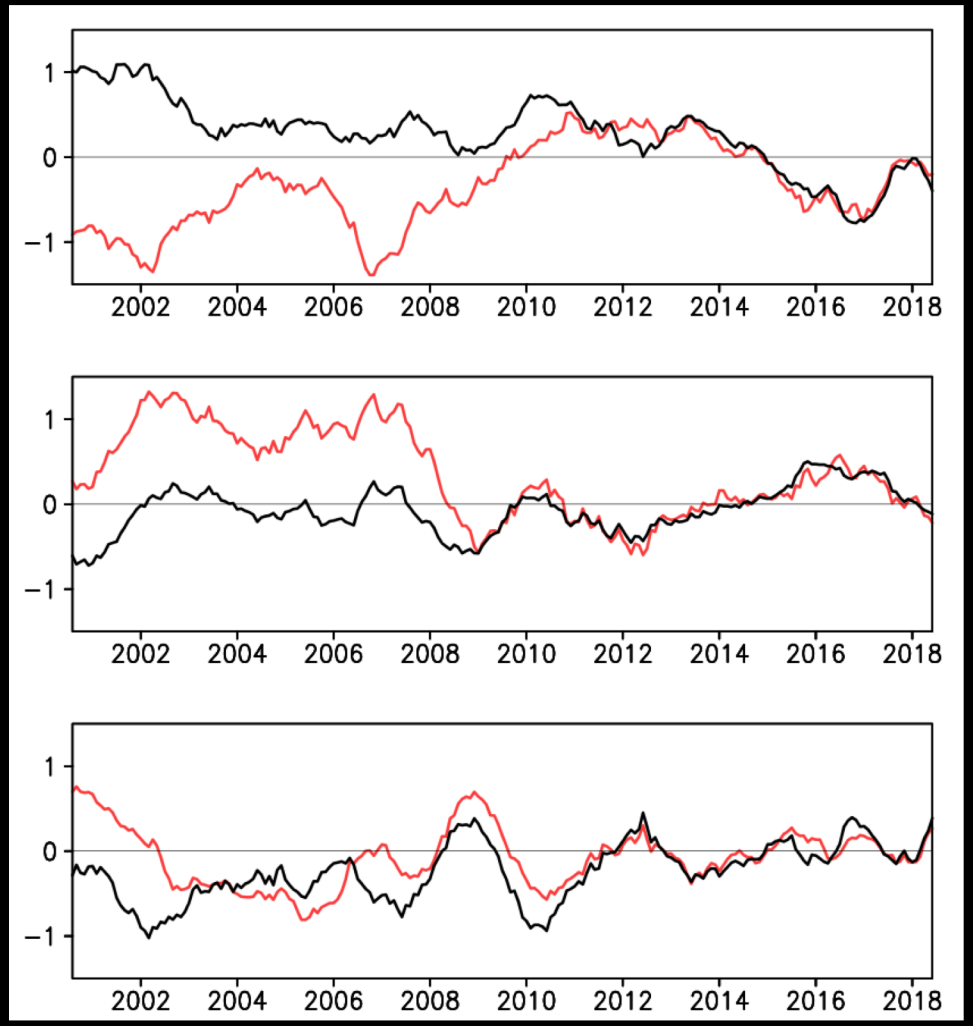
MERRA-2: Global mean of *deseasonalized* TOA all-sky radiative fluxes

Wrt 2011-2018Clim

SW↑

LW↑

Net↓



CERES **MERRA-2**

- Variations shown here are deviations from the post-2010 Clim, in order to highlight the pre-2010 vs. post-2010 differences.

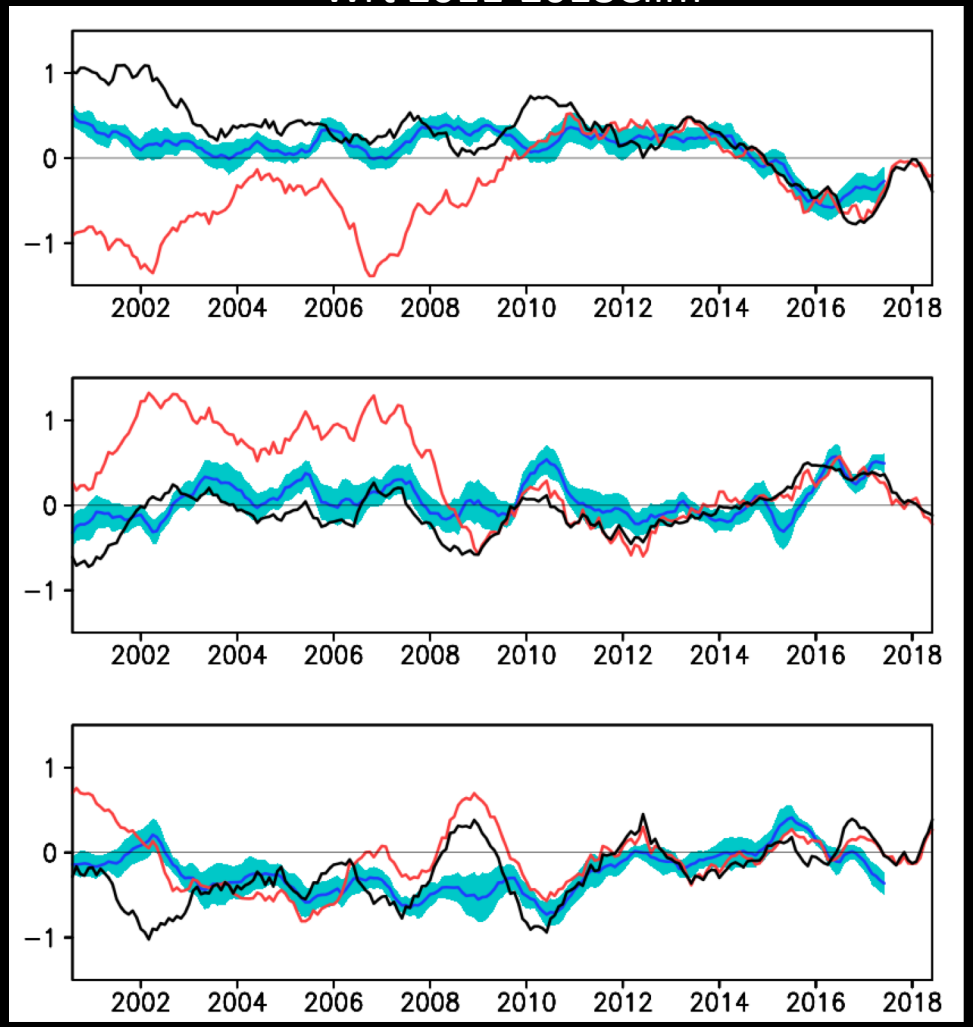
MERRA-2: Global mean of *deseasonalized* TOA all-sky radiative fluxes

Wrt 2011-2018Clim

SW↑

LW↑

Net↓



CERES **MERRA-2** **M2AMIP**

- M2AMIP performs considerably better than MERRA-2, suggesting that the pre-2010 vs. post-2010 differences in MERRA-2 could be due to the changes in the MERRA-2 observing systems.

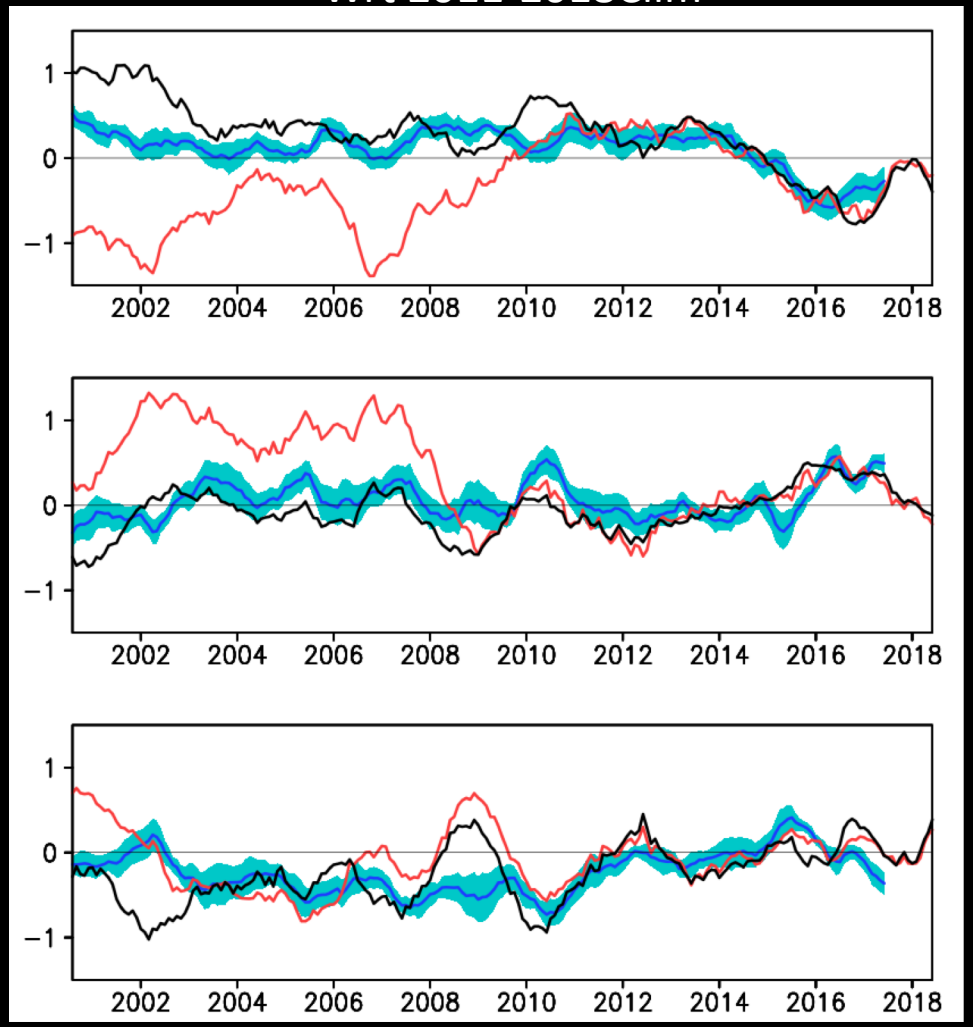
MERRA-2: Global mean of *deseasonalized* TOA all-sky radiative fluxes

Wrt 2011-2018Clim

SW↑

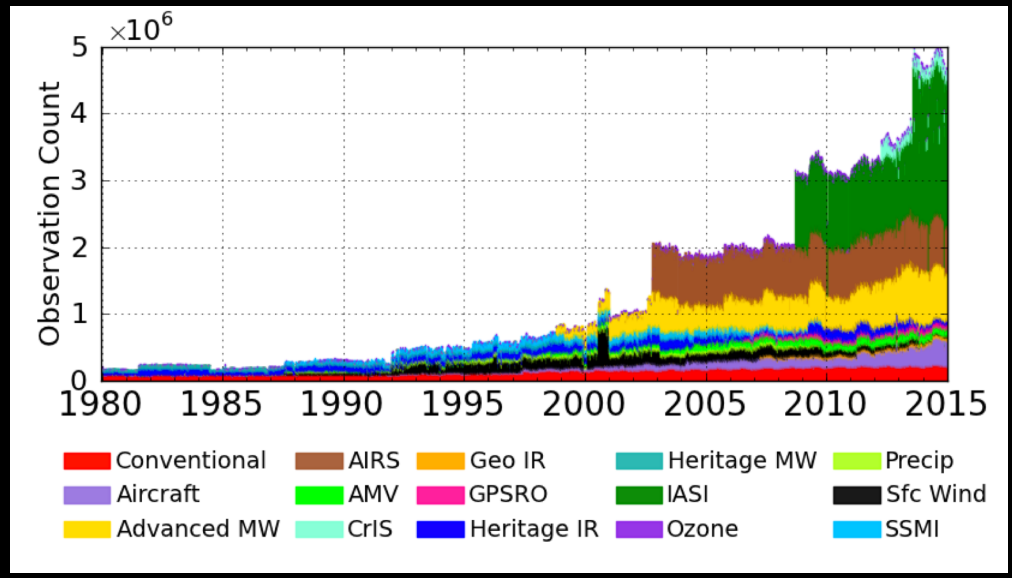
LW↑

Net↓



CERES **MERRA-2** **M2AMIP**

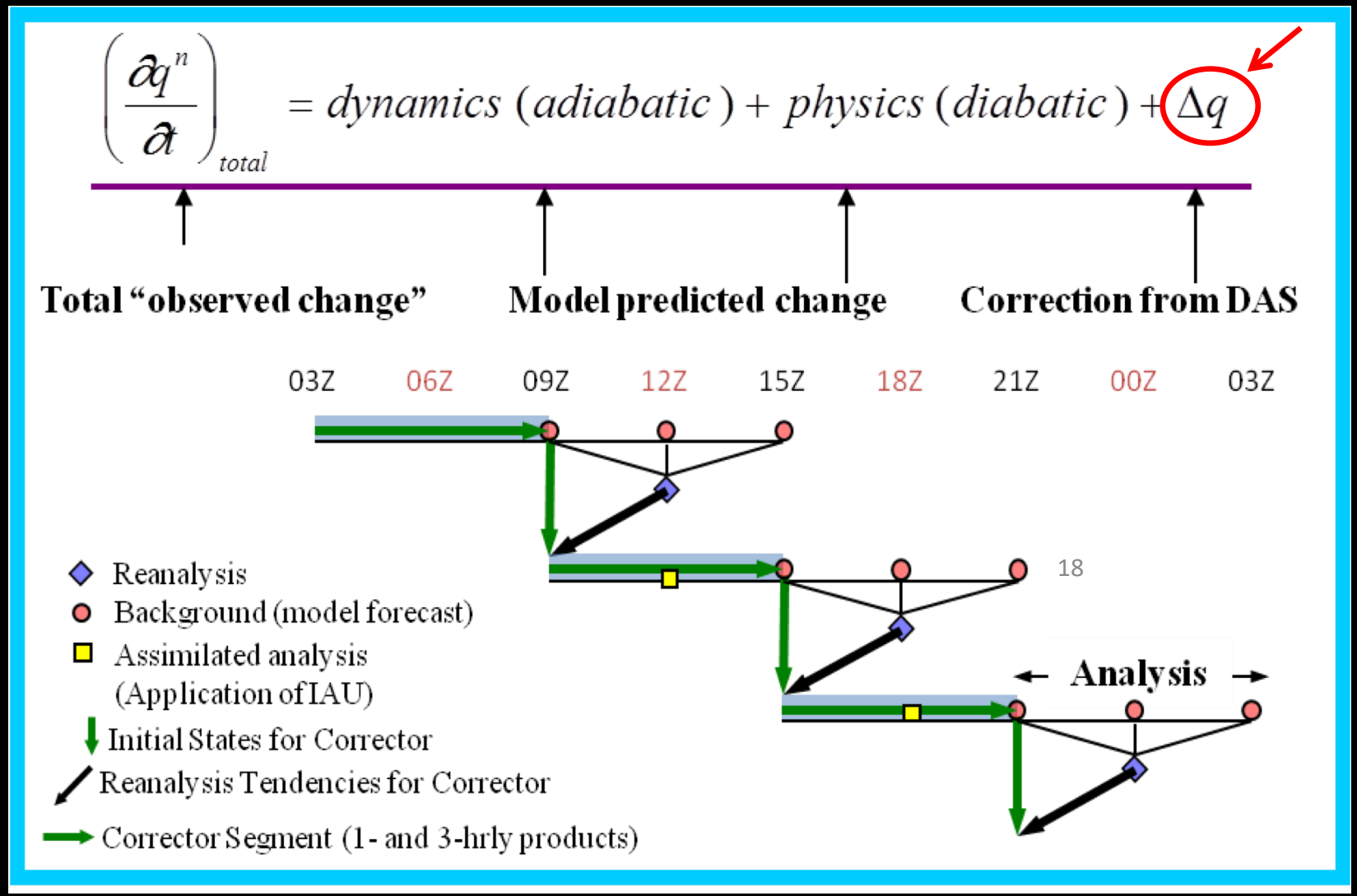
MERRA-2: assimilated observations



- The observations assimilated in MERRA-2 vary considerably with time (McCarty *et al.* 2016)

- M2AMIP performs considerably better than MERRA-2, suggesting that the pre-2010 vs. post-2010 differences in MERRA-2 could be due to the changes in the MERRA-2 observing systems.

MERRA-2: Incremental Analysis Update (IAU) Procedure



- MERRA-2 uses an incremental analysis update (IAU) to constrain the atmospheric model by observations

Tendencies due to analysis (***Δq***):

- reflect the impact of the assimilated observations
- quantify model bias (relative to the assimilated observations) but with an opposite sign

Bloom *et al.* (1996)

MERRA-2: Incremental Analysis Update (IAU) Procedure

$$\left(\frac{\partial q^n}{\partial t}\right)_{total} = dynamics\ (adiabatic) + physics\ (diabatic) + \Delta q$$

Total "observed change" | Model predicted change | Correction from DAS

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Tendencies due to analysis (***Δq***):

- reflect the impact of the assimilated observations
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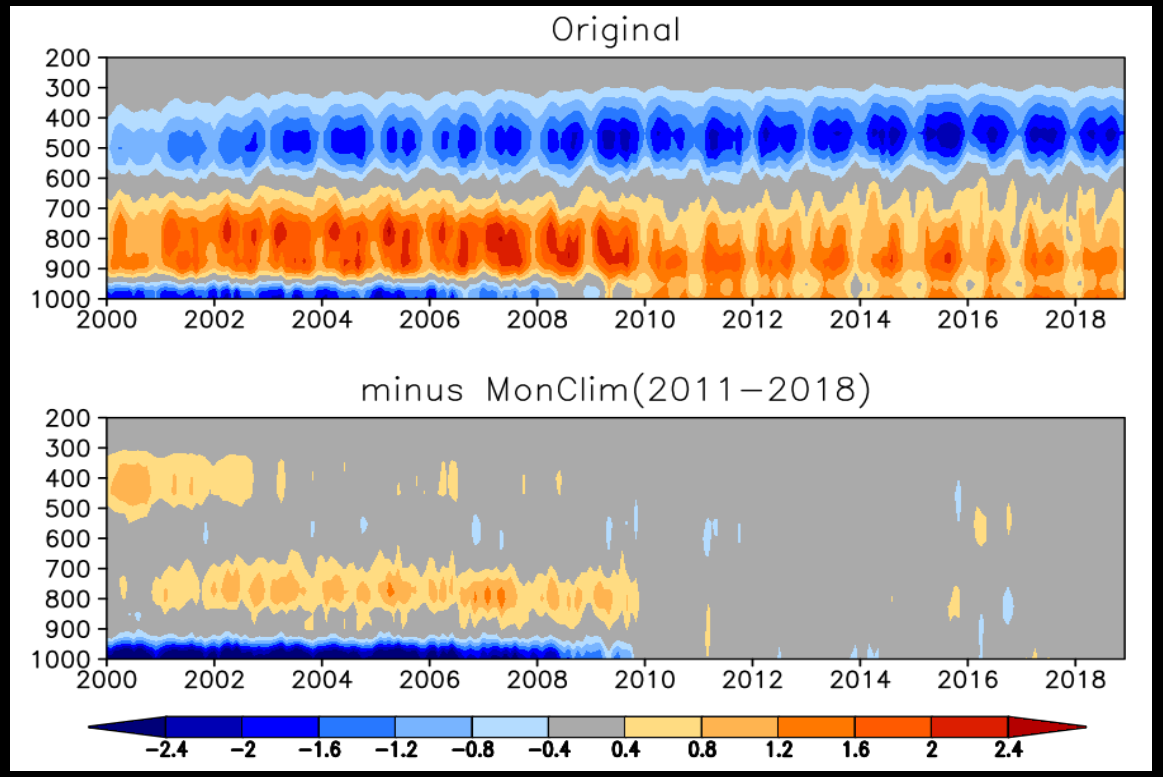
M2AMIP (AMIP simulations using MERRA-2 AGCM)

$$\left(\frac{\partial q^n}{\partial t}\right)_{total} = dynamics\ (adiabatic) + physics\ (diabatic)$$

MERRA-2: Impact of changes in input observing systems

Tendency of specific humidity (Q) due to analysis



- Relative to post-2010, the obs data assimilation in MERRA-2 during pre-2010 tends to i) remove model moisture near surface, ii) add more moisture in the mid-lower troposphere, and iii) remove less moisture in the mid-upper troposphere.
- Mainly due to the SSM/I dropout between 2006 and 2009 (Will McCarty, NASA/GMAO).

MERRA-2: Impact of changes in input observing systems

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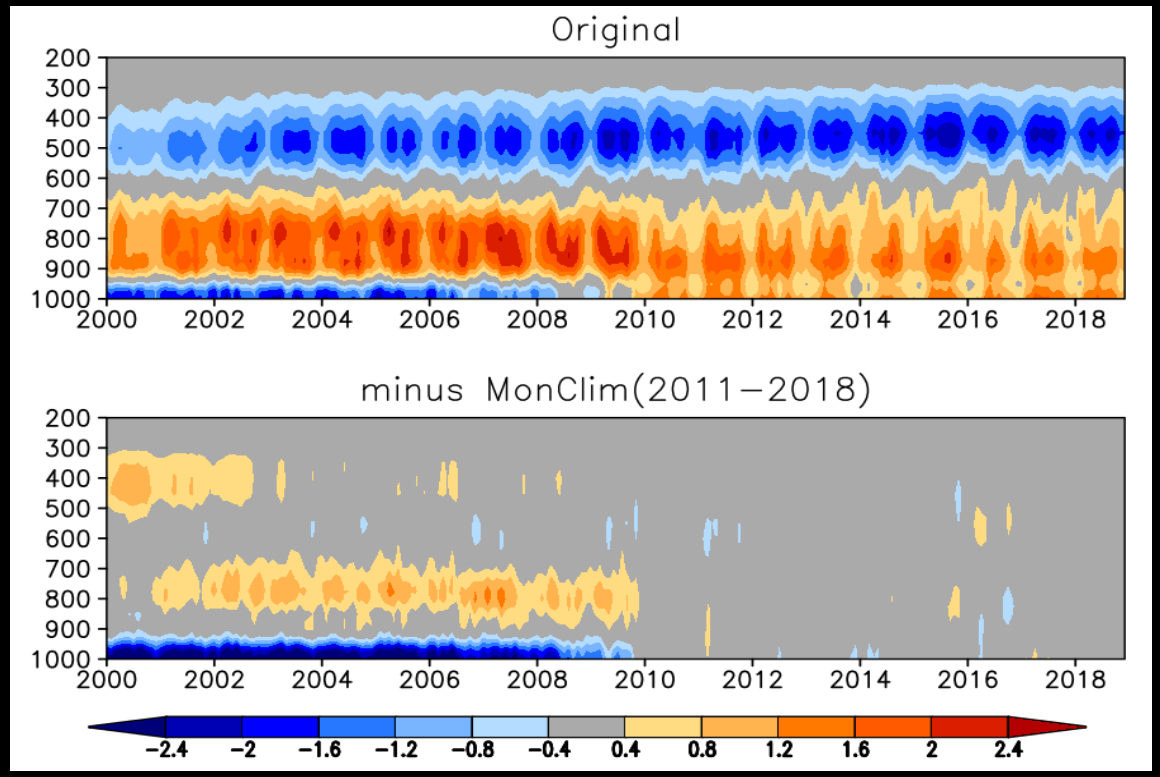

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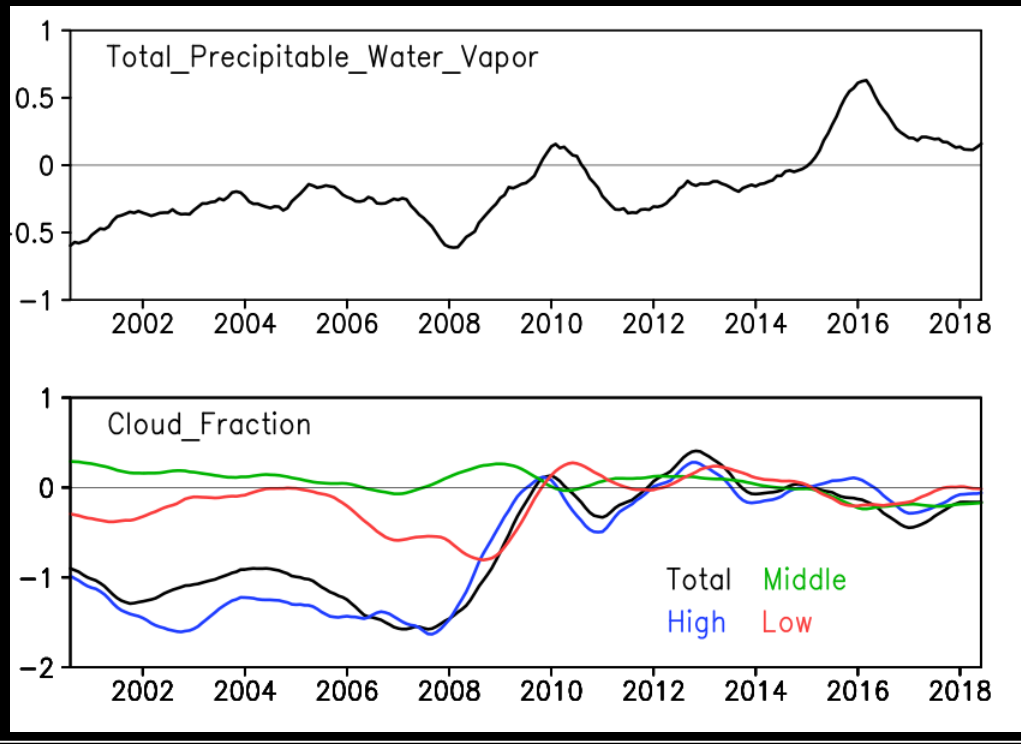
Atmos_Water_Vapor and Cloud_Fraction



- In response to the changes in the analysis increments, NASA GEOS-5 AGCM produces different clouds and TOA radiative fluxes:
  - Relative to post-2010, pre-2010 has less total atmospheric water vapor and total (primarily high) cloud fraction => less TOA SW↑ and more OLR.

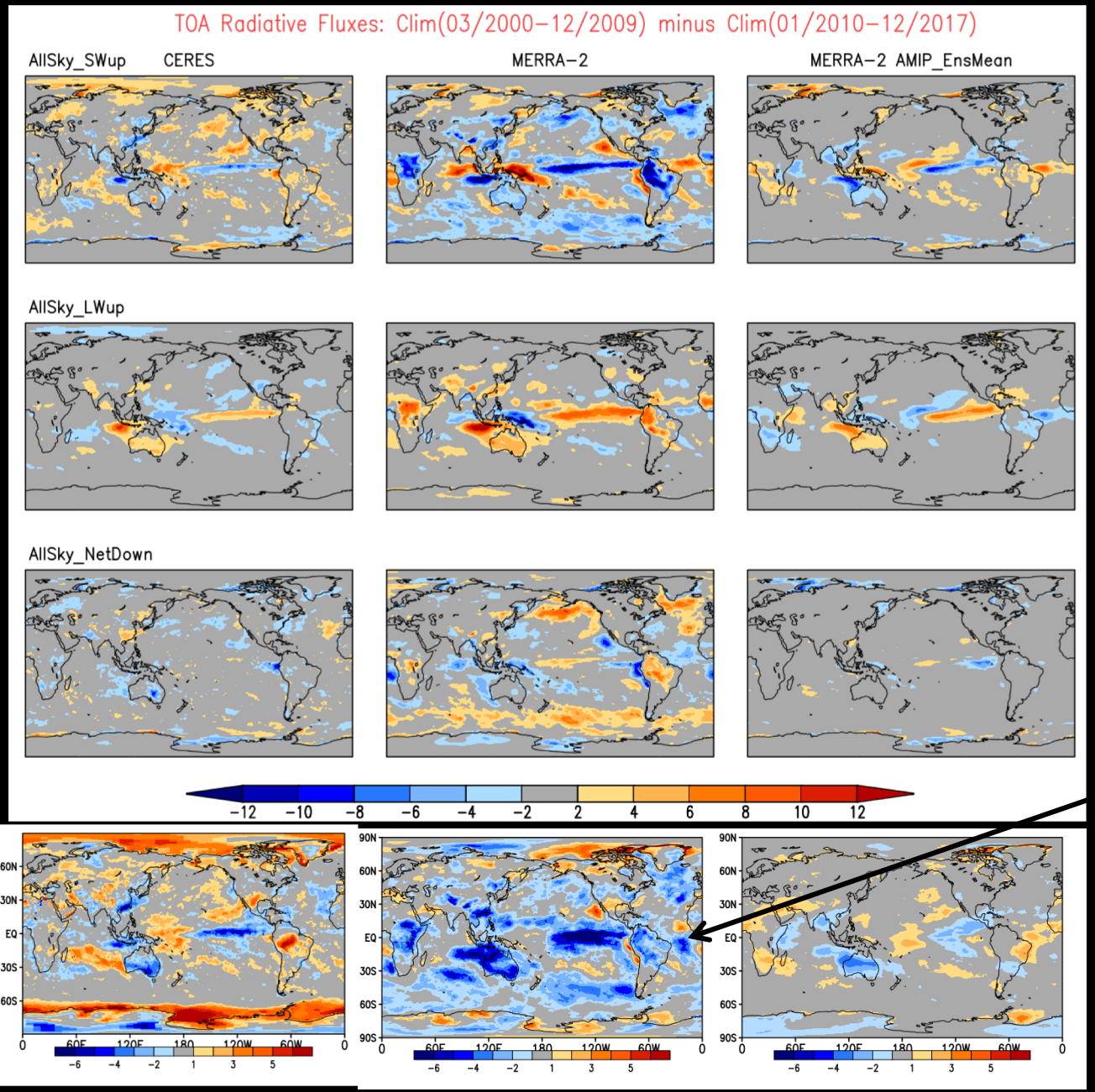
Pre-2010 Clim minus Post-2010 Clim

SW↑

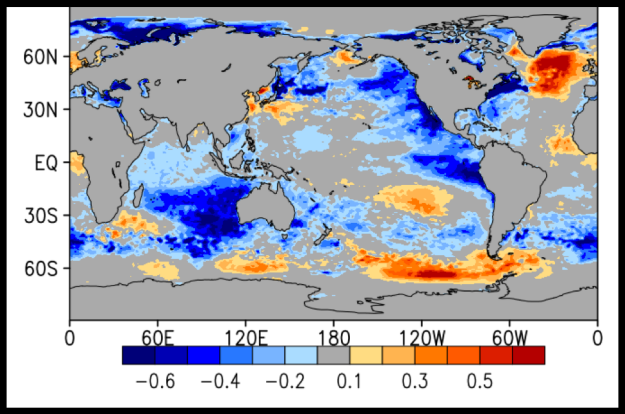
LW↑

Net↓

Total Cloud Cover



SST



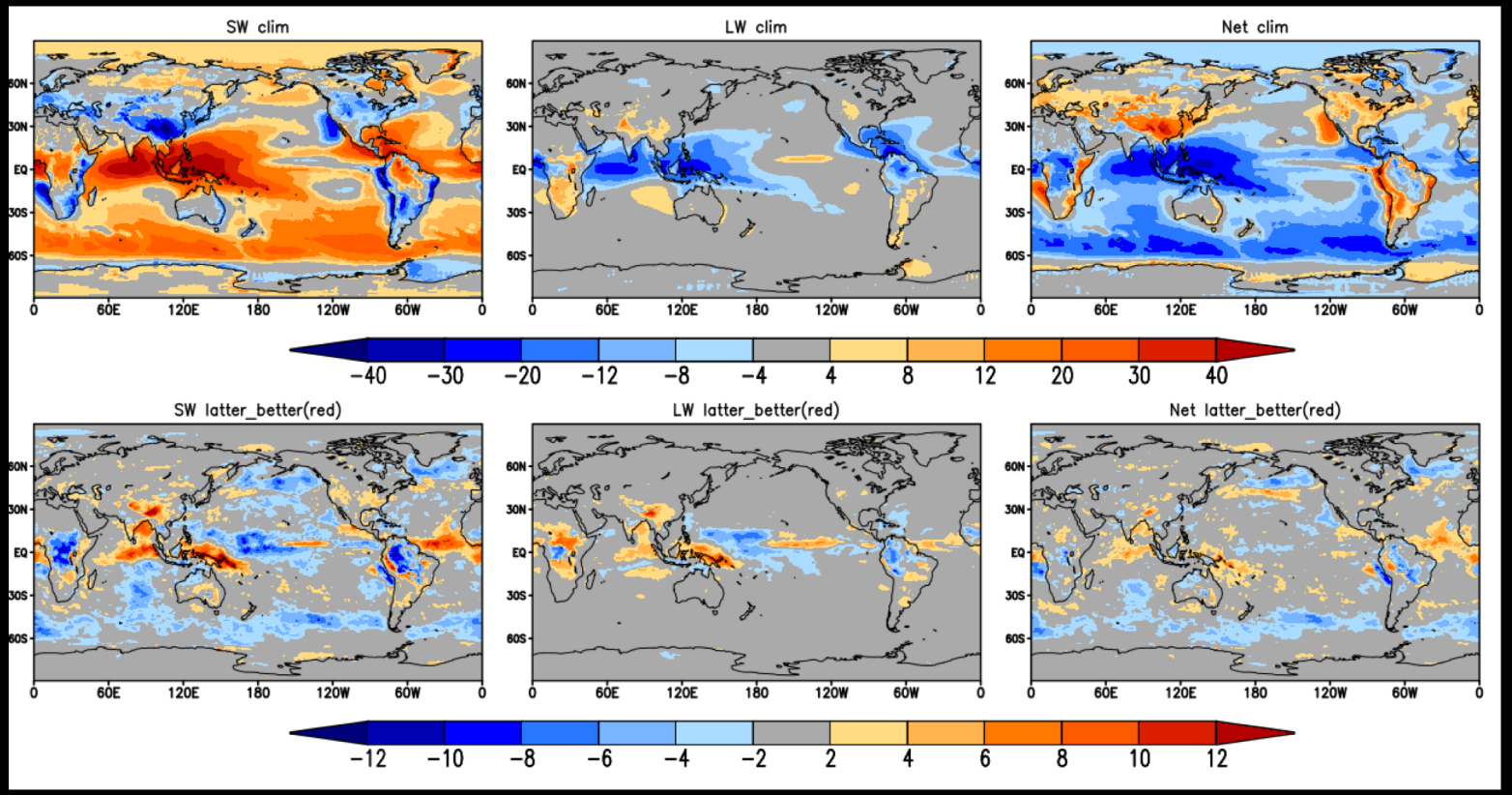
- MERRA-2 tends to produce less clouds than CERES and M2AMIP during 2000-2009.

Which is better (closer to CERES): pre-2010 or post-2010?

MERRA-2 – CERES
(Clim2003-2018)

Closeness to CERES
Pre-2010 vs. Post-2010

SW↑ LW↑ Net↓



Closeness to CERES:
|pre-2010 – CERES| – |post-2010 – CERES|
Pre-2010 better; Post-2010 better

➢ Post-2010 is better than pre-2010 over the Maritime continent and SE Asia, but is not as good elsewhere.

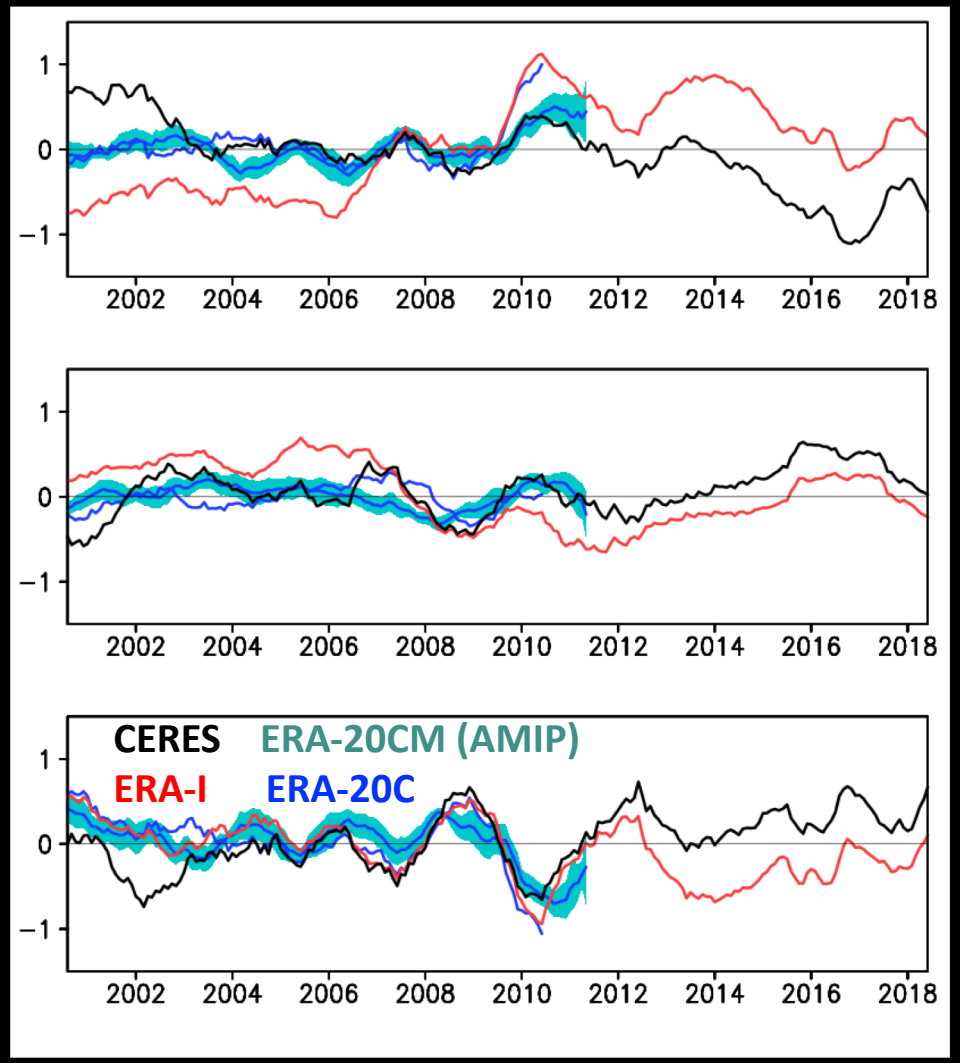
ERA-Interim: Global mean of *deseasonalized* TOA all-sky radiative fluxes

Wrt 2003-2010Clim

SW↑

LW↑

Net↓



- ERA-20C and ERA-20CM (AMIP) show considerably better agreement with CERES than ERA-Interim.

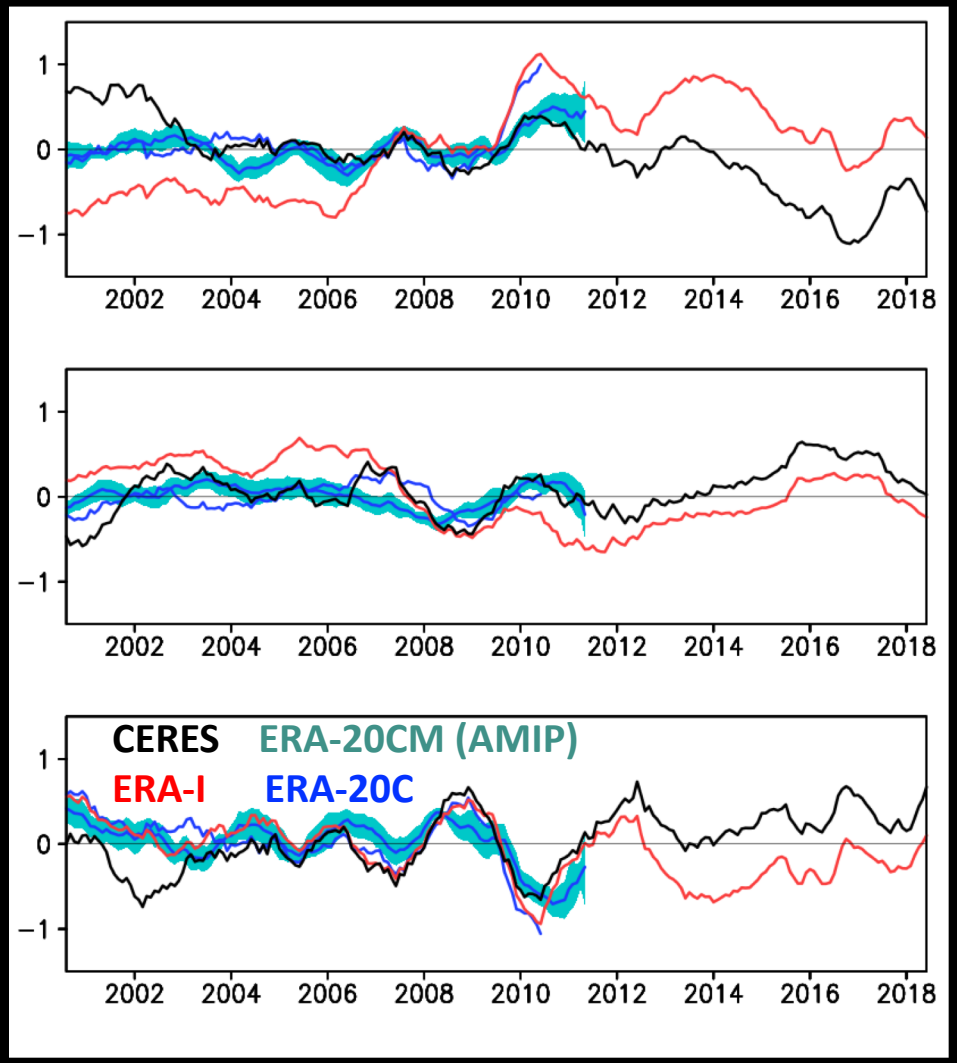
ERA-Interim: Impact of changes in input observing systems

Wrt 2003-2010Clim

SW↑

LW↑

Net↓



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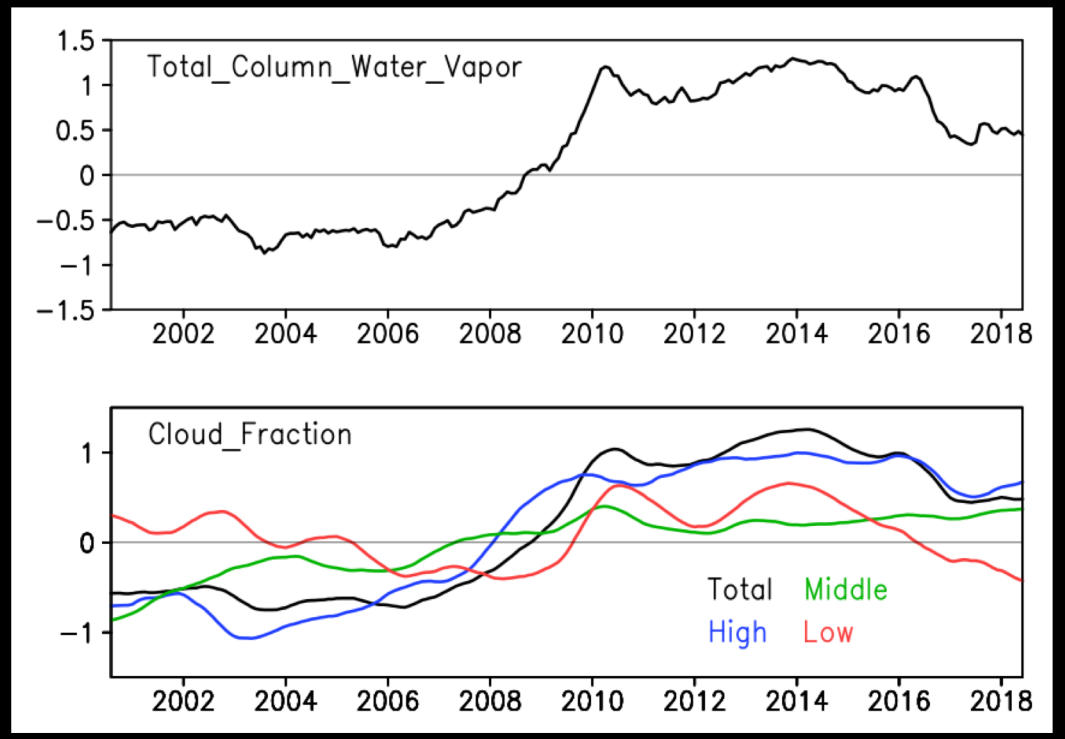
Wrt 2003-2010Clim



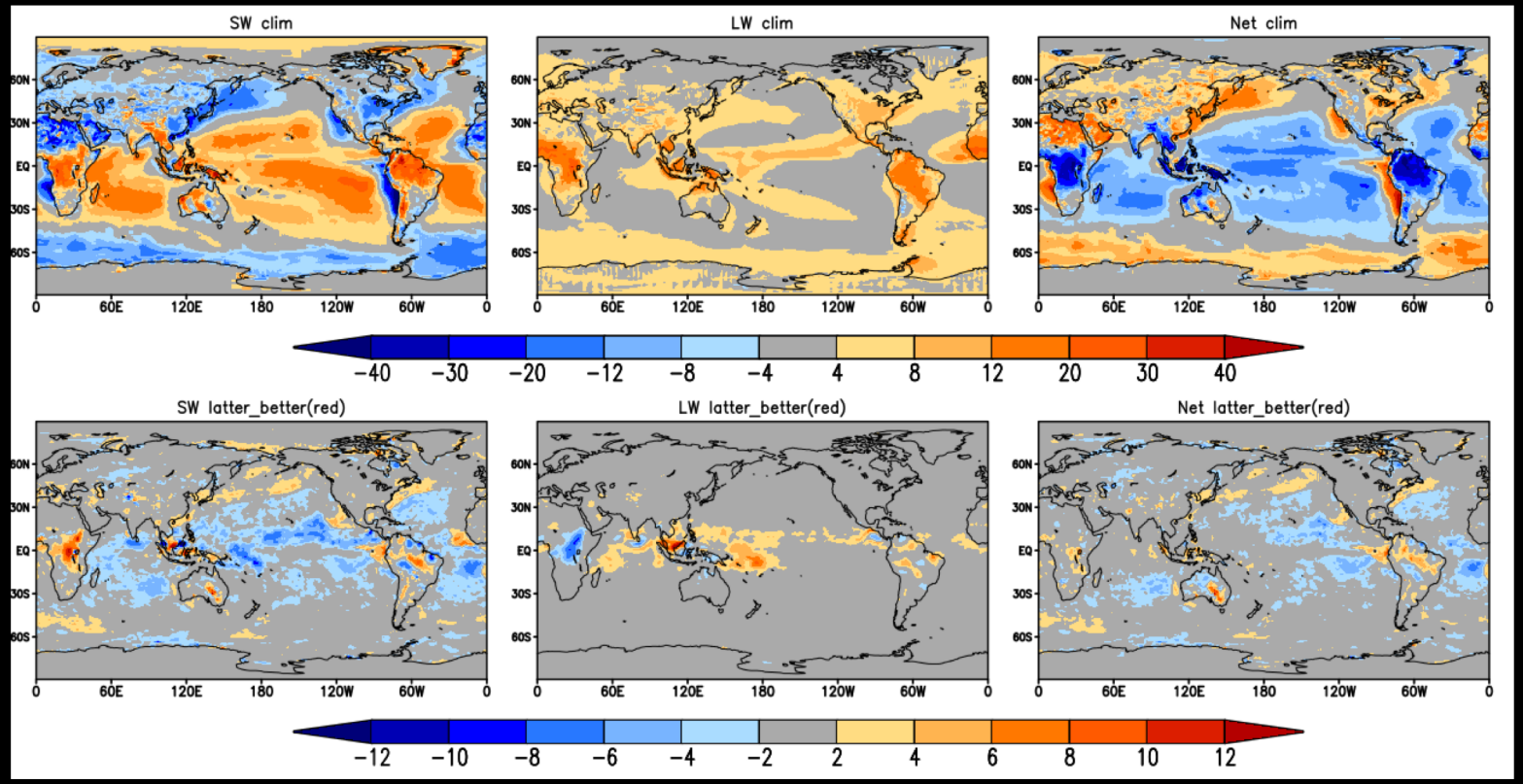
➢ Despite their differences in the assimilating models, data assimilation approach and observations assimilated, ERA-Interim is similar to MERRA-2 in that it has less atmospheric water vapor and clouds, and hence less TOA SW↑ and more OLR, during pre-2010 than during post-2010.

Which is better (closer to CERES): pre-2010 or post-2010?

ERA-I – CERES
(Clim2003-2018)

Closeness to CERES
Pre-2010 vs. Post-2010

SW↑ LW↑ Net↓



Closeness to CERES:
|pre-2010 – CERES| – |post-2010 – CERES|
Pre-2010 better; Post-2010 better

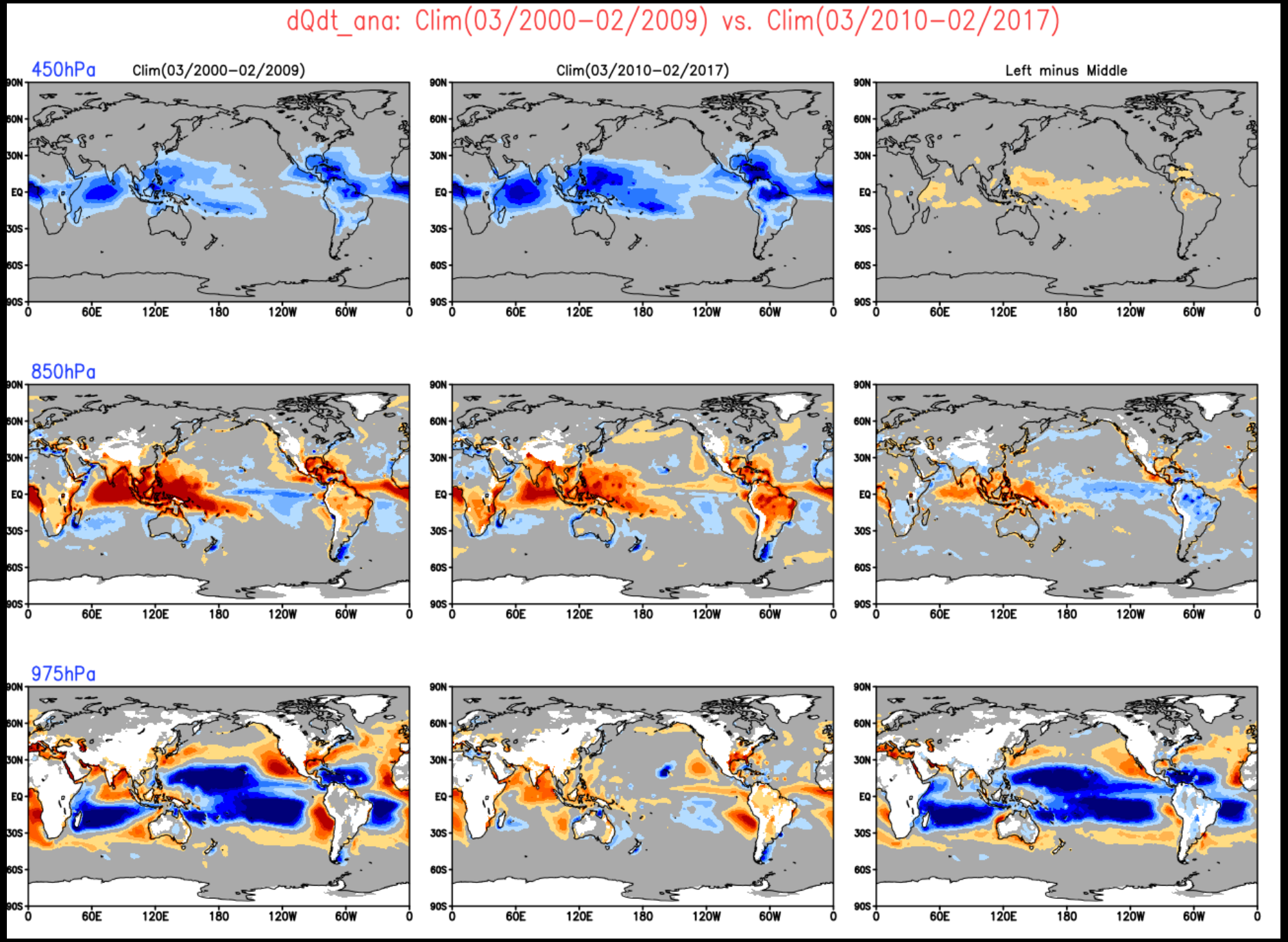
➢ Post-2010 is better than pre-2010 for LW↑, but is not as good for SW↑ and Net↓

Conclusions

The variations of TOA radiative fluxes in current reanalyses are influenced by the changes in their input observing systems, as well as various biases in the assimilating models (e.g. over low clouds regions, polar regions).

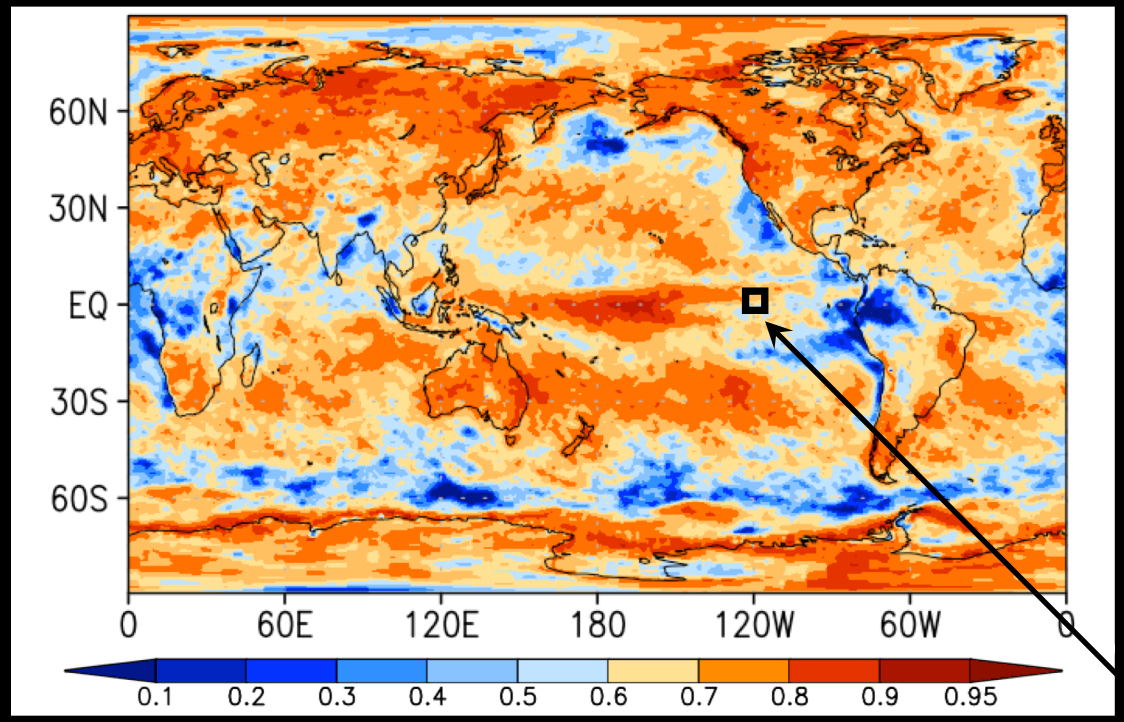
- The assimilation of different observations impacts the reanalysis production of atmospheric water vapor, clouds and hence TOA radiative fluxes.
  - The impact is similar in ERA-Interim and MERRA-2.
- ERA5 improves considerably upon reanalyses of earlier generations.
- AMIP simulations (e.g. M2AMIP, ERA-20CM, CMIP6) and reanalyses (e.g. ERA-20C) that assimilate consistent surface observations perform considerably better.
- Need to use caution when using reanalyses for TOA radiation energy budget studies.

Extra slides


dQdt_ana: Clim(03/2000–02/2009) vs. Clim(03/2010–02/2017)
450hPa
Clim(03/2000–02/2009)
Clim(03/2010–02/2017)
Left minus Middle
850hPa
975hPa
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W

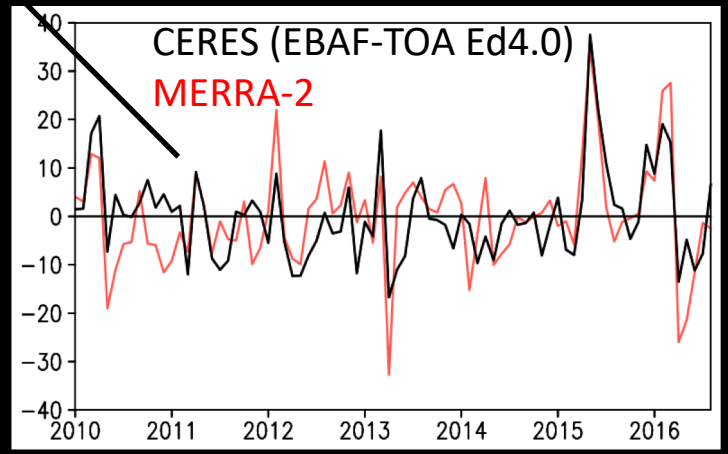
Temporal correlation between deseasonalized anomalies at each gridbox

TOA SWall↑: tcorr (CERES, MERRA-2)

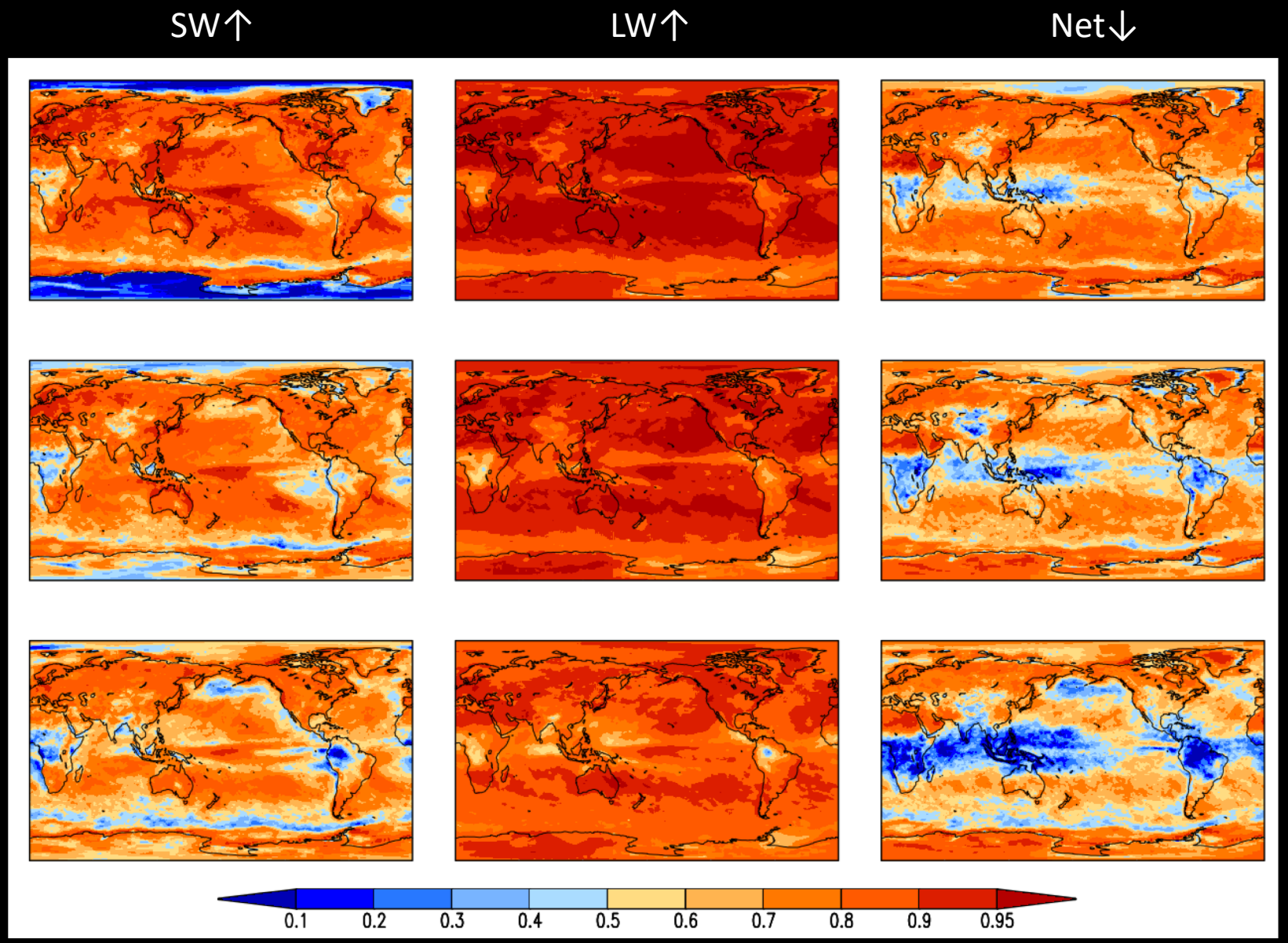


- By assimilating observations, reanalyses have identical time signature as the observations. This can be seen in the high temporal correlation in most of the global regions.

TOA SWall↑ at 120W0N
tcorr (CERES, MERRA-2): 0.70



Temporal correlation between deseasonalized anomalies at each gridbox



- Good temporal correspondence over much of the global regions, except over regions where the assimilating models are deficient in simulating observed cloud and radiative processes